

SNOWPACK DISTRIBUTION IN GRAND TETON NATIONAL PARK

and Snake River Drainage above Jackson, Wyoming



Phillip Farnes, Carolyn Heydon and Katherine Hansen
Department of Earth Sciences
Montana State University
Bozeman, MT 59717
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To
Dr. Robert Schiller
Chief, Division of Science and Natural Resource Management
National Park Service
Grand Teton National Park
Moose, Wyoming

Report Prepared by
Phillip Farnes¹, Carolyn Heydon² and Dr. Katherine Hansen³
Montana State University
Department of Earth Sciences
Bozeman, Montana 59717

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¹Research Scientist, ²Research Associate,
and ³Professor and Principal Investigator, Department of Earth Sciences, MSU

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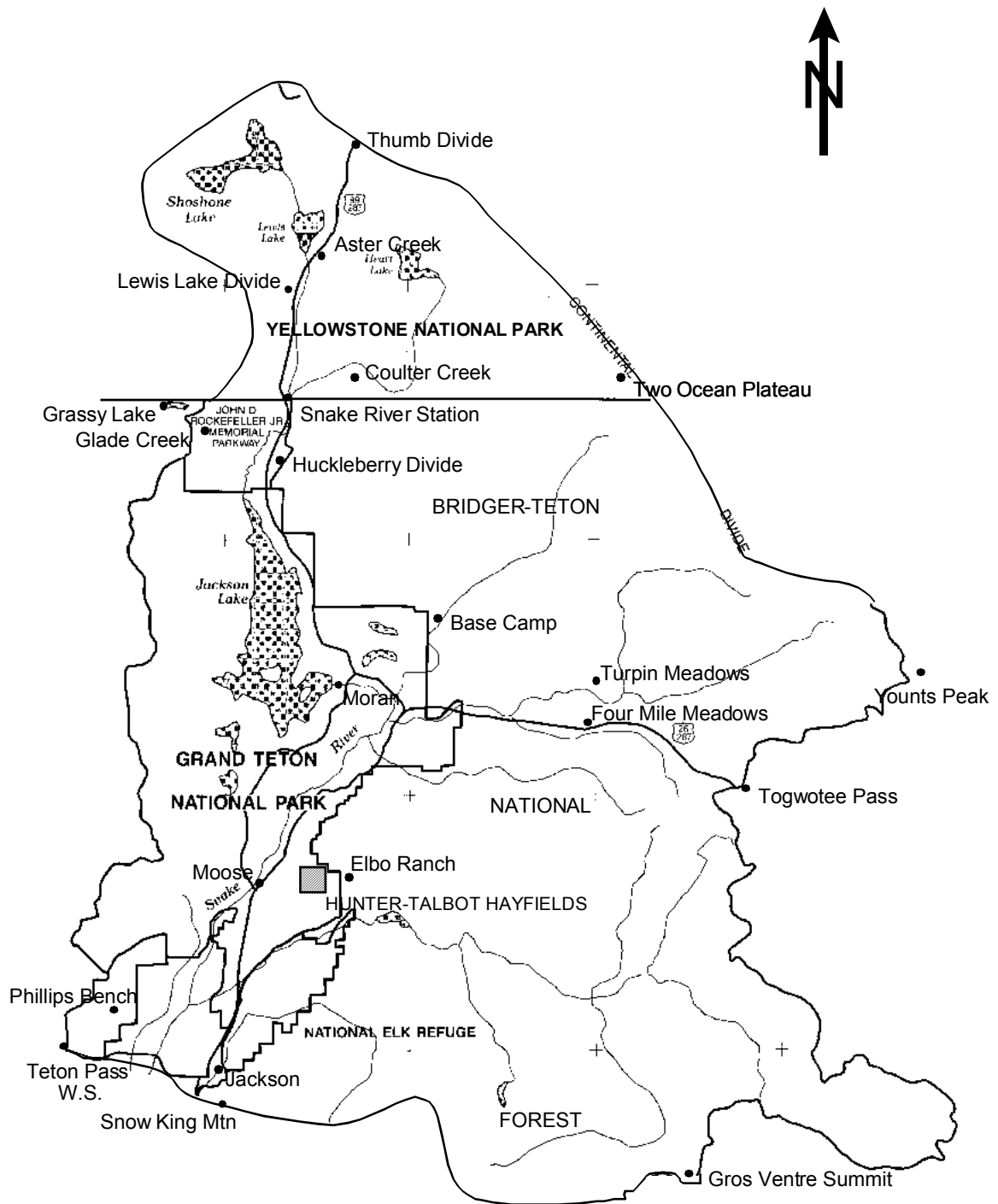


Figure 1. The study area includes the Snake River drainage north of Jackson, Wyoming.

INTRODUCTION

This report includes data and narrative from all previous reports on the research project "Snowpack Distribution in Grand Teton National Park, Wyoming". This study's objective is to process historic data on snowpack distribution across the Snake River drainage above Jackson, Wyoming (Figure 1), and more specifically across the lower elevations of Grand Teton National Park (GTNP) and the National Elk Refuge (NER), including the Hunter-Talbot hayfields area. Data on snowpack are related to the movement of bison (*Bison bison*), moose (*Alces alces shirasi*), elk (*Cervus elaphus*), and mule deer (*Dama hemionus*) to winter ranges. In addition to snow data, daily precipitation and temperature data were processed for future correlation with soil moisture, forage production, plant phenology and other plant/soil moisture/animal responses. Variability in other natural processes, such as recovery from disturbance, may also be correlated to variations in snow, precipitation, and/or temperature.

The snow pack distribution in and around Grand Teton National Park affects the migrations of large ungulates from their summer ranges in Grand Teton National Park, in Yellowstone National Park and in the Gros Ventre-Buffalo Fork drainage of the Bridger-Teton National Forest. Snow also affects the ungulates' ability to forage and travel. Of particular concern are the 400± bison (1997) that summer in small groups, mostly within GTNP. When the herd became free ranging in 1969, there were less than 10 animals. From 1969 to 1975, these animals wintered along the Snake River bottoms north of Moose and on the Kelly hayfields. By 1975 there were nearly 20 bison in the herd and they started wintering on the National Elk Refuge. The movement was possibly related to heavy snow in the 1975-76 winter and termination of haying and irrigation of the hayfields. By 1980, there were nearly 40 bison in the herd and they began utilizing supplemental feed on the NER. Since 1980, most of the bison now travel to the NER before the beginning of winter snowfall. Snowpack data was studied from the Hunter-Talbot hayfields on Antelope Flats east of Moose to determine if adequate winter forage would be available for bison to winter there instead of the NER.

HISTORY OF SNOW AND CLIMATOLOGICAL MEASUREMENTS

Within the Snake River drainage above Jackson, Wyoming, there are numerous sites where seasonal or daily data have been collected on snow, precipitation and temperature. A tabulation of data available at these sites is shown in Table 1.

Snow Courses

Snow courses (SC) are permanently marked locations where snow depth and snow water equivalent (SWE) measurements are manually collected at the first of each month (usually from January through April). Five to ten snow samples are taken at a specific location, and the average of these measurements is recorded as the measurement for that snow course. This program is coordinated by the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). Many agencies and individuals help obtain these data, including the U.S. Bureau of Reclamation (USBR), NRCS, National Park Service and the Teton Science School. Data are reported and archived by NRCS and are available through the NRCS computer in Portland, Oregon, or through the local NRCS office in Jackson, Wyoming, or the State NRCS Snow Survey office in Casper, Wyoming. The first snow course measurements were made in 1919 to forecast runoff into Jackson Lake, Wyoming. Many other snow courses were established in the 1930s primarily for forecasting irrigation water supplies.

Presently there are ten snow courses measured in and adjacent to Grand Teton National Park (Table 2). Snow course measurements for 1996-1998 have been tabulated in Appendix 1.

SNOTEL Sites

SNOTEL sites are automated stations that collect and transmit daily snow water equivalent (from snow pillows), total precipitation (accumulated from October 1 each year), and air temperatures year around (Table 3). Many are located at snow course sites and are operated and maintained by NRCS. Real-time and historic data for these sites are available through the NRCS computer in Portland, Oregon. Data collection at most sites began in the early 1980s. Monthly snow water equivalent at most of the snow pillows has been back-estimated from historic snow course data. There were eleven active SNOTEL sites in the study area when this study began, but Coulter Creek was discontinued at the end of September 1996. Three additional automated sites (data not available through the SNOTEL system) are operated and maintained by USBR in Moran, Wyoming, and Boise, Idaho (Table 3). Most of these USBR sites started collecting data in the 1991 water year. First-of-the-month SWE for snow pillow sites from 1996-1998 are shown in Appendix 1

Table 1. Data sites in or near Snake River drainage above Jackson, Wyoming, and snow water equivalent records available.

Site Name and Data Type	Elev. (ft)	Coordinates		Data and Years Available
		UTME	UTMN	
Arizona Creek (SC; Disc)	6820	528.2	4869.1	1-4, 1919-1985
Aster Creek (SC)	7750	529.7	4902.8	1-4, 1919-present
Base Camp (SNOTEL)	7030	544.5	4865.4	Daily, 1981-present
Base Camp (SC; Disc)	7030	544.5	4865.2	1-4, 1930-1996
Blackrock (SC; Disc)	8900	573.2	4846.5	2-4, 1936-1982
Coulter Creek (SNOTEL; Disc)	7020	534.0	4890.5	Daily, 1981-1996
Coulter Creek (SC; Disc)	7020	534.0	4890.5	2-4, 1919-1993
Elbo Ranch (SC)	7100	532.7	4835.1	2-4, 1976-present
Four Mile Meadows (SC)	7860	558.8	4852.1	2-4, 1936-present
Glade Creek (USBR)	7040	521.1	4882.8	Daily, 1991-present
Glade Creek (SC)	7040	521.1	4882.8	1-4, 1919-present
Grassy Lake (SNOTEL)	7265	514.2	4885.8	Daily, 1981-present
Grassy Lake (SC; Disc)	7270	514.3	4886.0	1-6, 1940-1992
Gros Ventre Summit (SNOTEL)	8755	570.5	4804.2	Daily, 1981-present
Gros Ventre Summit (SC; Disc)	8750	570.5	4804.2	2-4, 1948-1992
Huckleberry Divide (USBR)	7300	525.0	4876.8	Daily, 1991-present
Huckleberry Divide (SC)	7300	525.0	4876.8	1-4, 1919-present
Jackson (CLIM)	6230	519.3	4814.3	Daily, 1949-present
Lewis Lake Divide (SNOTEL)	7860	526.8	4894.5	Daily, 1981-present
Lewis Lake Divide (SC; Disc)	7850	526.8	4894.5	1-6, 1919-1992
Moose (CLIM)	6468	522.9	4833.4	Daily, 1949-present
Moran (USBR)	6750	533.4	4855.9	Daily, 1991-present
Moran (CLIM)	6798	533.1	4855.8	Daily, 1949-present
Moran (SC)	6750	533.4	4855.9	1-4, 1919-present
Moran Bay (SC; Disc)	6810	520.7	4857.1	2-4, 1919-1982
Phillips Bench (SNOTEL)	8200	508.2	4818.1	Daily, 1981-present
Phillips Bench (SC; Disc)	8200	508.2	4818.1	2-4, 1973-1991
Pitchstone Plateau (AM; Disc)	8520	521.6	4898.2	2-4, 1965-1982
Snake River Station (SNOTEL)	6920	526.7	4886.6	Daily, 1990-present
Snake River (CLIM)	6882	526.7	4886.6	Daily, 1949-present
Snake River Station (SC)	6920	526.7	4886.6	1-4, 1919-present
Snow King Mountain (SC)	7660	519.6	4811.9	2-4, 1959-present
Teton Pass W.S.(SC)	7740	502.7	4816.3	2-4, 1973-present
Thumb Divide (SNOTEL)	7980	534.0	4912.5	Daily, 1988-present
Thumb Divide (SC)	7980	534.0	4912.5	1-4, 1938-present
Togwotee Pass (SNOTEL)	9580	575.0	4844.6	Daily, 1981-present
Togwotee Pass (SC; Disc)	9580	575.0	4844.6	1-6, 1936-1991
Two Ocean Plateau (SNOTEL)	9240	562.3	4888.8	Daily, 1981-present
Turpin Meadows (SC)	6900	558.2	4856.1	2-4, 1936-present
Younts Peak (SNOTEL)	8350	594.9	4864.8	Daily, 1981-present

Data Types: SC= Snow Course; Disc = Discontinued; SNOTEL = Snow Survey Telemetry; USBR = U.S. Bureau of Reclamation Telemetry; CLIM = Climatological Station; AM = Aerial Marker; 1-4 indicates monthly readings on January 1, February 1, March 1, and April 1.

Table 2. Active snow courses in and adjacent to Grand Teton National Park.

Site No.	Site Name	Elev (ft)	Coordinates			
			UTME	UTMN	LAT	LONG
10E08	Aster Creek	7750	529.7	4902.8	44-17	110-38
10F28	Elbo Ranch	7100	532.7	4835.1	43-40	110-36
10F06	Four Mile Meadows	7860	558.8	4852.1	43-49	110-16
10E13	Glade Creek	7040	521.1	4882.8	44-00	110-44
10E14	Huckleberry Divide	7300	525.0	4876.8	44-03	110-41
10F04	Moran	6750	533.4	4855.9	43-52	110-34
10E12	Snake River Station	6920	526.7	4886.6	44-08	110-40
10F20	Snow King Mountain	7660	519.6	4811.9	43-28	110-46
10F24	Teton Pass WS	7740	502.7	4816.3	43-30	110-59
10F05	Turpin Meadows	6900	558.2	4856.1	43-51	110-17

Table 3. SNOTEL and USBR snow pillow sites in and adjacent to Grand Teton National Park.

Site No.	Site Name	Elev. (ft)	Coordinates			
			UTME	UTMN	LAT	LONG
10F02S	Base Camp	7030	544.5	4865.4	43-56	110-26
10E10S	Coulter Creek	7020	534.6	4890.5	44-10	110-34
10E13S	Glade Creek (USBR)	7040	519.5	4883.3	44-00	110-44
10E15S	Grassy Lake	7270	514.2	4885.8	44-08	110-50
10F19S	Gros Ventre Summit	8750	570.6	4804.3	43-23	110-08
10E14S	Huckleberry Divide (USBR)	7300	525.0	4876.8	44-03	110-41
10E09S	Lewis Lake Divide	7860	526.8	4894.5	44-12	110-40
10F04S	Moran (USBR)	6750	533.4	4855.9	43-52	110-34
10F23S	Phillips Bench	8200	508.2	4818.1	43-31	110-55
10E12S	Snake River Station	6920	526.7	4886.6	44-08	110-40
10E07S	Thumb Divide	7980	534.0	4912.5	44-22	110-34
10F09S	Togwotee Pass	9580	575.0	4844.6	43-45	110-03
10E19S	Two Ocean Plateau	9240	562.3	4888.8	44-09	110-13
09F18S	Younts Peak	8350	594.9	4864.8	43-56	109-45

Climatological Stations

Currently, there are four climatological (CLIM) stations in the study area (Table 4). Data are manually collected at these sites, including daily precipitation, maximum and minimum air temperatures, snowfall and depth of snow on the ground. Historic data for these climatological sites is available from 1949 to the present through the NRCS computer in Portland. Records prior to 1949 exist for these stations but are not currently available through electronic means.

Table 4. Climatological stations in and adjacent to Grand Teton National Park.

Site No.	Site Name	Elev. (ft)	Coordinates			
			UTME	UTMN	LAT	LONG
4910	Jackson	6230	519.30	4814.3	43-29	110-46
6428	Moose	6468	522.9	4833.4	43-40	110-43
6440	Moran	6798	533.1	4855.8	43-51	110-35
8315	Snake River	6882	526.7	4886.6	44-08	110-40

Estimates were made of the daily SWE using data from precipitation gages. If the mean daily temperatures were below 32°F, precipitation was recorded as snow. When the mean daily temperatures were above 32°F, the degree-days (above 32°F) were calculated and multiplied by a melt-rate to estimate the daily melt. Melt-rates (based on unpublished studies at snow pillows in Montana) in inches per degree-day (°F) for the study were estimated to be 0.08 for October, 0.05 for November, 0.02 for December and January, 0.05 for February, 0.08 for the first 15 days of March, and 0.10 for the last 15 days of March. The late-season melt-rate was calculated by dividing the SWE at the time melt started plus any precipitation received between start of melt and melt-out, by the sum of the degree-days from start of melt to melt-out. This calculated melt-rate diminishes the snow at a rate whereby the SWE drops to zero on the day the snow depth is zero.

For most valley stations, unpublished data from Yellowstone National Park and data from this study indicates that the SWE values from the manual snow measurements are comparable to the SWE estimated from climatological records. For areas having heavier snowfall, the measured SWE may be as much as 10 percent greater than calculated SWE values probably due to under-catch of snowfall. Numerous studies have shown that precipitation gages under-catch (thus under-measure) precipitation when the precipitation is in the form of snow. Generally the error of under-catch becomes larger when the snowfall is less dense and when the rate of snowfall is more intense. Sublimation also reduces the snowpack throughout the winter.

SWE was estimated for climatological stations shown in Table 4. The Moose station was moved from Beaver Creek to its present location at headquarters in 1959. Records gathered at Beaver Creek from 1949-1959 were adjusted to be compatible with records from the present location. At Snake River, there is a snow course, SNOTEL and a CLIM site. Snow water equivalent values from 1949-1989 were estimated from CLIM records and then adjusted to first-of-the-month snow course values so the data will be comparable to that collected at the present pillow location. Starting in 1990, SWE was obtained from the snow pillow. First-of-the-month estimates of SWE for 1996-1998 are shown in Appendix 1.

Supplemental Measurements

Supplemental manual snow measurements were taken at over 40 locations in the winters of 1996, 1997 and 1998 (Table 5) to evaluate the snowpack distribution between the more widely spaced climatological stations, snow courses, and SNOTEL stations to validate the GIS snow distribution model. Most supplemental measurements were made in flat and open locations; however, a few measurements were made on various slopes and aspects to validate slope/aspect relationships. Because of the large number of sites, it was not always possible to obtain supplemental measurements on the first of the month when regular snow courses were measured. By using daily snow pillow SWE and SWE estimates from climatological stations, it was possible to estimate the SWE for February 1, March 1, and April 1 at the supplemental sites so the data for the three winters could be compared with those from the long-term stations. The SWE first-of-the-month estimates at the supplemental sites have been tabulated in Appendix 2. The actual snow measurements made near the first of the month are on file at the Science and Natural Resource Management office at Grand Teton National Park in Moose, Wyoming.

Table 5. Supplemental snow measurement sites in and adjacent to Grand Teton National Park.

Site No.	Site Name	Elev. (ft)	Coordinates		Slope Degree	Aspect True Azimuth
			UTME	UTMN		
01	Boys Ranch	6484	519.18	4831.64	0	
02	Death Canyon	6479	518.91	4831.62	0	
03	R Lazy S	6466	518.33	4830.63	0	
03A	R Lazy S Lower	6466	518.33	4830.63	33	161
03B	R Lazy S Top	6466	518.33	4830.63	30	161
04	Wilson Road	6443	517.36	4829.69	0	
05	Moose W.S.	6485	522.98	4833.44	0	
06	Beaver Creek	6649	521.47	4836.72	0	
07	Blacktail Butte	6537	524.57	4834.26	0	
08	Deadmans Bar Rd	6829	531.12	4844.66	0	
08A	Deadmans Bar Sign	6840	531.15	4844.55	0	
08B	Deadmans Bar Sign	6840	531.15	4844.55	5	230
08C	Deadmans Bar Sign	6840	531.15	4844.55	10	230
08D	Deadmans Bar Sign	6840	531.15	4844.55	19	270
08E	Deadmans Bar Sign	6840	531.15	4844.55	11	170
08F	Deadmans Bar Sign	6840	531.15	4844.55	21	190
09	Moosehead Ranch	6870	536.83	4848.15	0	
10	N. Elk Ranch	6776	539.25	4752.90	0	
11	Buffalo R.S.	6747	539.18	4854.38	0	
12	Oxbow Bend	6763	536.48	4856.86	0	
12A	Oxbow Bend	6880	537.05	4856.85	23	211
12B	Oxbow Bend	6870	537.05	4856.85	14	158
12C	Oxbow Bend	6890	537.05	4856.85	23	119
13A	Buffalo Valley Rd	6902	544.87	4853.78	12	319
13B	Buffalo Valley Rd	6868	544.65	4853.79	17	319
13C	Buffalo Valley Rd	6831	544.73	4853.71	17	249
13D	Buffalo Valley Rd	6868	544.65	4853.79	19	261
13E	Buffalo Valley Rd	6868	544.65	4853.79	15	183
13F	Buffalo Valley Rd	6868	544.65	4853.79	17	233
14	Road 30083	6828	545.74	4854.83	0	
14A	Road 30083	6840	545.74	4854.83	15	172
14B	Road 30083	6840	545.74	4854.83	23	159
15	Buffalo Run	6845	546.59	4855.19	0	
16	KOA Picnic Area	6813	548.18	4853.11	0	
17	Black Rock R.S.	6913	552.21	4852.30	0	

Table 5. (continued)

Site No.	Site Name	Elev. (ft)	Coordinates		Slope Degree	Aspect True Azimuth
			UTME	UTMN		
18	Antelope Flat	6610	527.17	4834.62	0	
19	Mailbox Corner	6812	529.60	4835.55	0	
20	Schwering Studio	6750	529.62	4837.78	0	
21A	Lobo Hill	6991	531.93	4834.67	0	
21B	Lobo Hill	7220	532.40	4834.75	15	195
21C	Lobo Hill	7220	532.40	4834.75	15	193
21D	TSS Flat	6940	532.45	4835.10	0	
21E	TSS Mid	7040	532.55	4835.45	33	142
21F	TSS Upper	7060	532.55	4835.45	31	142
22	Highlands Jct	6702	530.45	4829.06	0	
23	Highlands Loop	6694	528.20	4828.73	0	
23A	Highlands Loop	6670	528.20	4828.73	10	141
23B	Highlands Loop	6670	528.20	4828.73	17	136
24	Airport	6448	521.49	4827.77	0	
25	Gros Ventre River	6544	524.72	4827.51	0	
26	Gros Ventre Turnout	6405	521.55	4823.16	0	
27	Fish Hatchery	6324	521.58	4820.20	0	
28	Jackson W.S.	6252	519.42	4814.49	0	
29	NER HQS	6298	520.48	4814.08	0	
30	Lupine Meadows	6699	522.09	4839.86	0	
31	Jenny Lake Lodge	7006	522.29	4847.72	0	
32	N. Jenny Lake Jct	6989	524.05	4848.37	0	
33	Sewage Ponds	6916	530.95	4852.04	0	
33A	Sewage Ponds	6916	530.95	4852.04	18	198
34	Moran Bay SC	6840	520.70	4857.00	0	
35	Pilgrim Creek	6917	533.86	4860.76	0	
36	Coulter Bay	6886	529.44	4861.97	0	
37	Lizard Creek	6825	525.38	4872.43	0	
38	Flagg Ranch	6868	526.54	4883.50	0	
39A	Hunters Hayfield WE	6860	529.79	4835.31	0	
39B	Hunters Hayfield WE	6860	529.89	4835.31	0	
39C	Hunters Hayfield WE	6920	530.99	4835.31	0	
39D	Hunters Hayfield WE	6920	531.09	4835.31	0	
39E	Hunters Hayfield WE	6920	531.19	4835.31	0	
39F	Hunters Hayfield WE	6920	531.29	4835.31	0	

Table 5. (continued).

Site No.	Site Name	Elev. (ft)	Coordinates		Slope Degree	Aspect True Azimuth
			UTME	UTMN		
39G	Hunters Hayfield WE	6920	531.49	4835.31	0	
39H	Hunters Hayfield WE	6920	531.49	4835.31	0	
40	Hunters Hayfield NS	6920	530.99	4835.51	0	
40A	Hunters Hayfield NS	6920	530.99	4835.41	0	
40B	Hunters Hayfield NS	6920	530.99	4835.31	0	
40C	Hunters Hayfield NS	6920	530.99	4835.21	0	
40D	Hunters Hayfield NS	6920	530.99	4835.11	0	
41	Bar BC Road	6679	522.12	4834.28	0	
42	Bar BC Road B	6670	523.42	4838.23	0	
42A	Bar BC Sage	6630	524.17	4838.83	10	216
42B	Bar BC Sage	6630	524.17	4838.83	14	221
42C	Bar BC Sage	6630	524.17	4838.83	17	233
43	Bar BC Mid	6650	523.92	4838.18	0	
44	Bar BC FP	6550	524.77	4837.98	0	
44A	Bar BC East	6630	524.25	4838.23	22	123
44B	Bar BC East	6630	524.25	4838.23	26	118
44C	Bar BC East	6630	524.25	4838.23	26	113
44D	Bar BC Upper	6650	524.24	4838.24	27	120
44E	Bar BC Upper	6650	524.24	4838.24	28	120
44F	Bar BC Upper	6650	524.24	4838.24	28	108
45	Bar BC Mid Rd	6670	523.02	4838.28	0	
46	RKO Road Flats	6840	531.45	4851.70	0	
47	RKO PL	6700	536.45	4859.50	0	
48	RKO Willow Flat	6690	535.50	4851.20	0	
49	Ski Base	6373	513.86	4825.94	0	
50	Phillips Canyon	6447	511.08	4820.82	0	

ADJUSTMENTS TO SNOW WATER EQUIVALENT

Snow water equivalent (SWE) measurements represent the amount of water stored in the snowpack at a specific time and location. At some sites, more than one type of snow measurement has been collected and different methods may yield different values of SWE. In the data analyses for this study, all SWE values were adjusted to represent near "true" SWE. No adjustments were made to snow pillow data as tests have shown that the butyl or hypalon snow pillows produce near "true" SWE. Manual snow samplers have an over-measurement bias related to the cutter design (Farnes *et al.*, 1983). SWE values obtained with a manual snow sampler having a standard federal cutter (like TSS sampler) were multiplied by 0.91 to obtain a "true" SWE. SWE obtained with snow tubes having a sharpened federal cutter (like all others used for the rest of the Snake River snow courses) was multiplied by 0.94 to obtain a "true" SWE. The SWE values shown in Appendix 2 have been adjusted to represent "true" SWE.

Estimates of SWE from climatological data are assumed to be near "true" SWE, due to a combination of under-catch of snow by precipitation gages and sublimation loss from the snowpack. In heavier snow areas (i.e., Snake River), SWE estimated from climatic data may be as much as 10 percent less than "true" SWE. SWE calculated from precipitation data at Jackson, Moose and Moran was assumed to approximate "true" SWE for this study (see previous section on climatological stations).

Typical long-term climate measuring stations are located in level and open areas that are not influenced by forest canopy. Therefore, to determine SWE on areas that are not level and/or that are forested required adjustments to the station data. A relationship between slope/aspect and SWE for the Northern Range in Yellowstone National Park was developed by Farnes and Romme (1993). Data from the 1996 Grand Teton National Park supplemental snow measurements and additional Yellowstone data were incorporated into the original Yellowstone data to develop a revised relationship between snowpack and slope/aspect for the upper Snake River drainage (Figure 2). The SWE for a flat and open pixel is determined by using the SWE at regular measuring sites and the appropriate algorithm to account each pixel's location and elevation. The SWE is then adjusted to account for the slope and aspect of that pixel using the equations from Table 6. The equations represent the mean for each 30 degree azimuth sector.

Snowpack under a forest canopy is less than the snowpack in non-forested areas during the snow accumulation period due to snow interception in the forest canopy and subsequent sublimation of the snow caught in the canopy. How much less is dependent on the type of trees and the density of the forest canopy. Snow in lodgepole pine (*Pinus cortorta*) stands accumulates differently than it does in spruce/fir (*Picea engelmanni/Abies lasiocarpa*) stands. Studies by Codd (1959), Farnes (1971, 1978, 1989), Hardy and Hansen-Bristow (1990), McCaughey et al. (1997), Moore and McCaughey (1997), and Skidmore et al. (1994) have been used to relate snowpack accumulation to habitat cover types as described by Despain (1990). The relationship of snowpack accumulation for lodgepole pine (Figure 3) and for spruce/fir (Figure 4) have been developed. Aspen (*Populus tremuloides*) and cottonwood (*Populus spp.*) stands are treated as openings since little snow is retained in the barren winter canopy. Whitebark pine (*Pinus albicaulis*) forests usually have a less dense canopy than lodgepole pine or spruce/fir and are typically in more wind-swept areas. Losses of SWE in the snowpack due to canopy interception by whitebark pine are assumed to be about 50 percent of that for spruce/fir, depending on stand density.

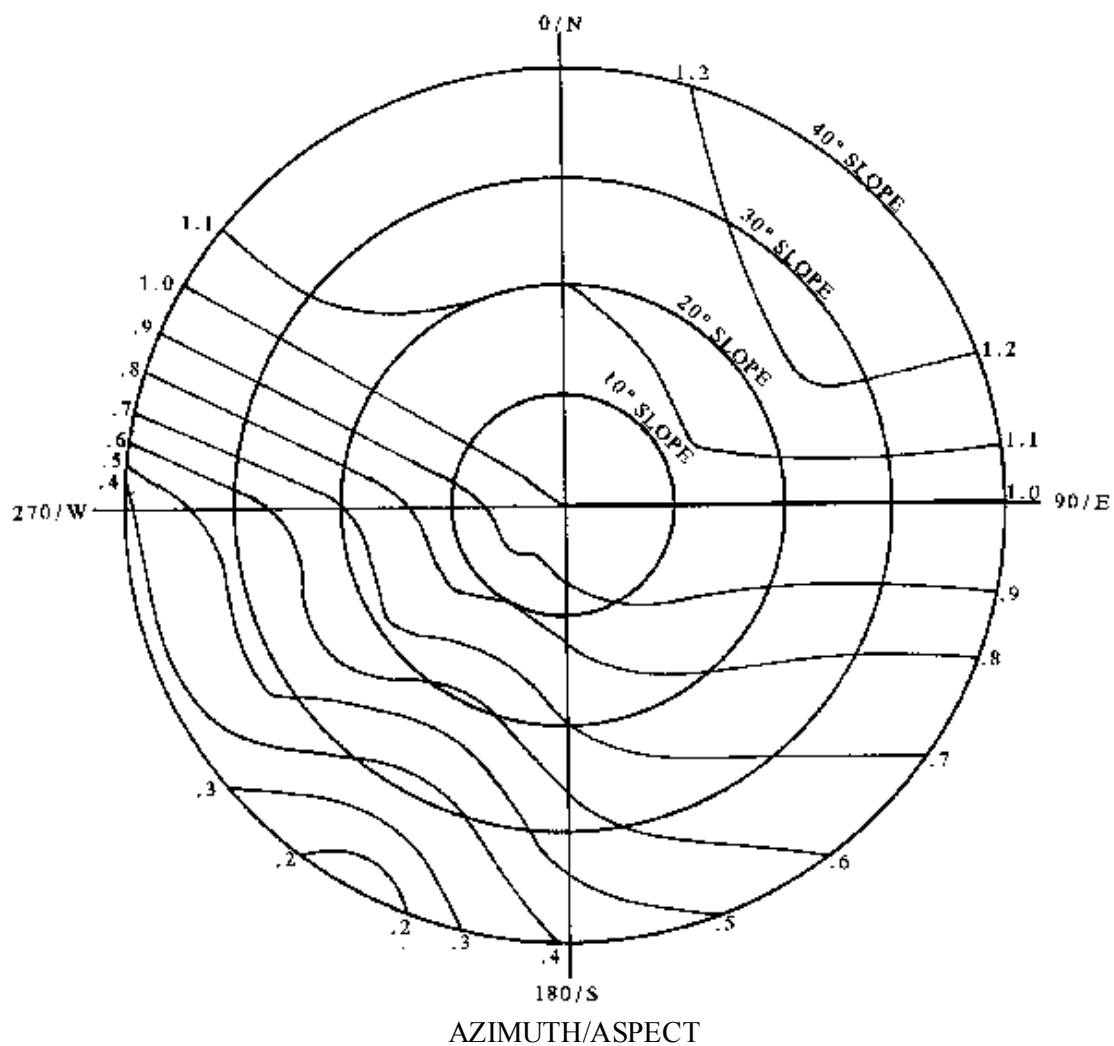


Figure 2. Snowpack and slope/aspect relationship for the upper Snake River drainage.

Table 6. Approximating equations for obtaining factors to adjust SWE to account for slope and aspect from Figure 2 by 30 degree azimuth sectors.

Azimuth Range°	Equation
15 - 44	$F = 1.0 + .0070 \times S$
45 - 74	$F = 1.0 + .0082 \times S$ (max F = 1.2)
75 - 104	$F = 1.0$
105 - 134	$F = 1.0 - .0070 \times S$
135 - 164	$F = 1.0 - .0115 \times S$
165 - 194	$F = 1.0 - .0155 \times S$
195 - 224	$F = 1.0 - .0222 \times S$
225 - 254	$F = 1.0 - .0155 \times S$
255 - 284	$F = 1.0 - .0155 \times S$
285 - 314	$F = 1.0$
315 - 344	$F = 1.0 + .0047 \times S$
345 - 14	$F = 1.0 + .0050 \times S$

F = Factor

S = Slope in degrees

Multiply SWE for flat, open location by factor to adjust for slope and aspect. True North equals 0° azimuth; True East equals 90° azimuth; True South equals 180° azimuth; True West equals 270° azimuth.

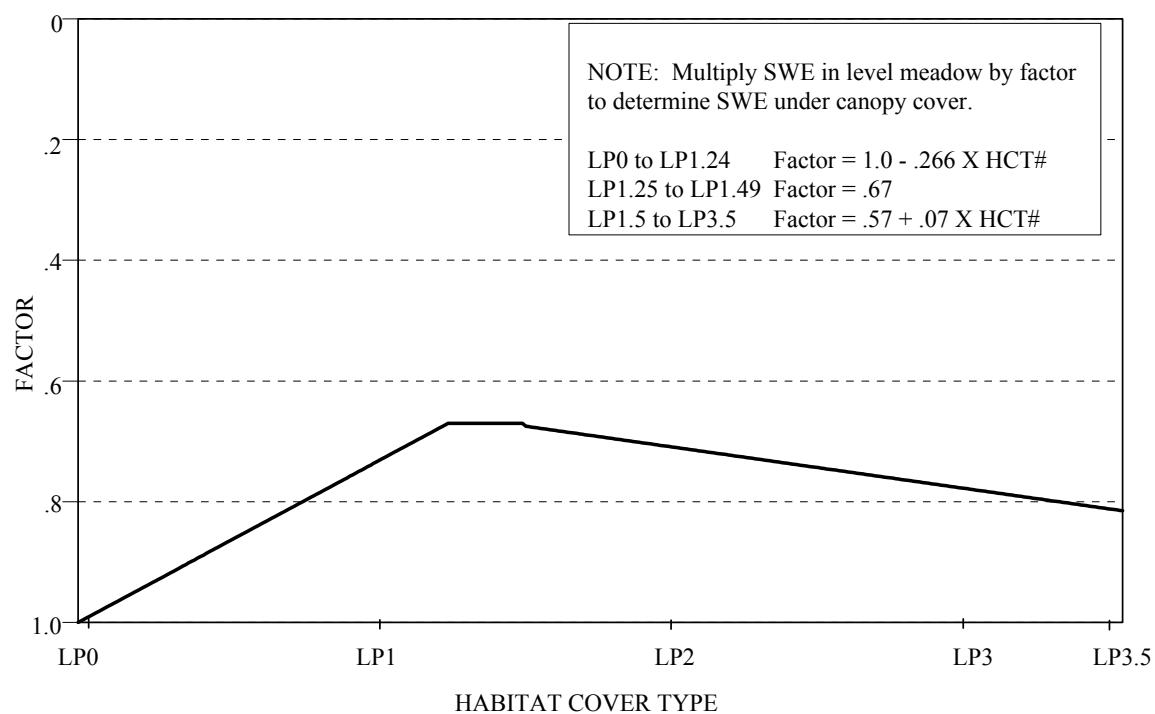


Figure 3. Relationship between snowpack accumulation and lodgepole pine cover types. (LP0 to LP3.5 refer to habitat cover types described by Despain, 1990).

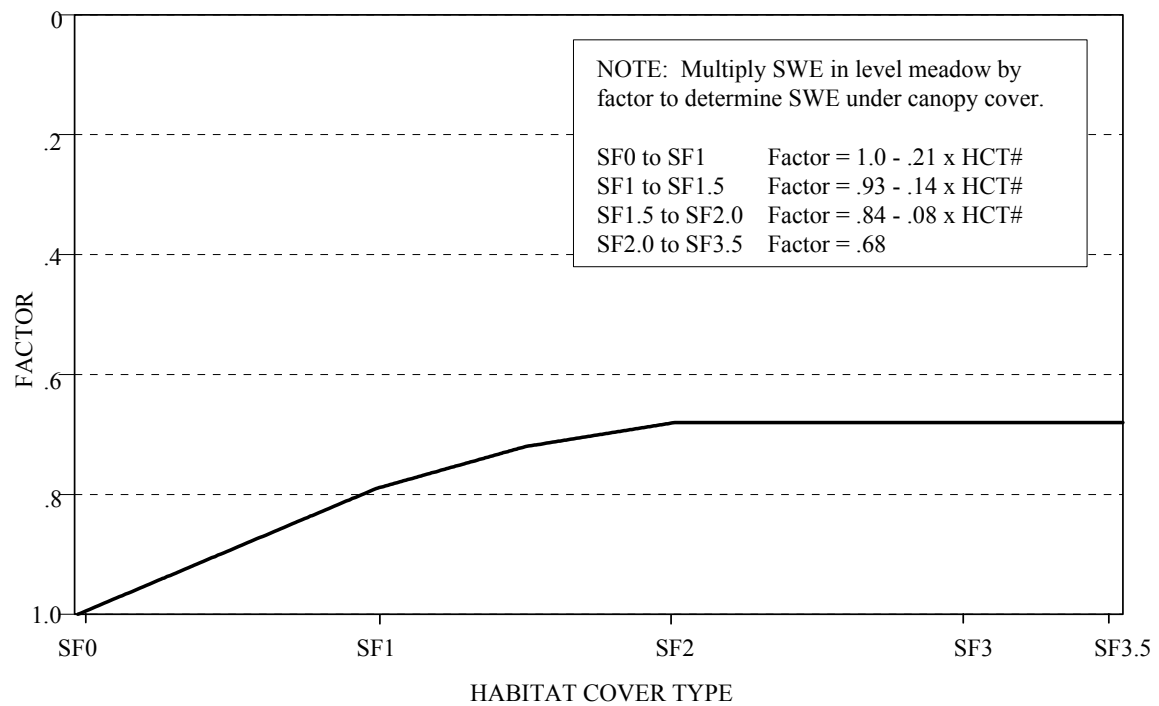


Figure 4. Relationship of snowpack accumulation and spruce/fir (SF0 to SF3.5 refers to habitat cover types described by Despain, 1990).

DATA FORMAT

Data from daily SNOTEL and climatological stations is on file in the Division of Science and Natural Resource Management office at Grand Teton National Park in Moose, Wyoming. Each station's data is in a consistent format on disk (Figure 5). All data is in water year (WY) format (starting on October 1 and going through September 30). For example, October 15, 1990, data is shown as 10-15-91 (1991 WY) and January 15, 1992 is shown as 01-15-92 (1992 WY).

Appendix 3 summarizes monthly data, useful for comparisons of various years and locations, which includes snow water equivalent, Keetch-Byram Drought Index (KBDI) values, and accumulated growing degree-days.

INFLUENCE OF OROGRAPHIC BARRIERS AND ELEVATION

Orographic uplifting of storms crossing mountain ranges results in increased precipitation on the upwind or windward side and just over the crest of mountain ranges, and less precipitation on the downwind or leeward side. Increases in SWE are magnified even more as air temperatures are lower at the higher elevations (so more precipitation falls in the form of snow), and melt occurs later and more slowly at higher elevations than at lower elevations. The Teton Mountain Range is extremely effective in orographic uplifting and in enhancing precipitation on the windward side (west-facing) and near the crest on east-facing slopes. Areas to the east and downslope of the Teton mountain crest receive substantially less moisture. North of the Tetons, near Yellowstone National Park, storms do not undergo major orographic uplift until they reach the Madison Plateau, Pitchstone Plateau and the Red Mountains. Considerably more precipitation falls along the windward side and just past the crest of these barriers compared to leeward areas. For example, the Thumb Divide site (a leeward site) on the Continental Divide is slightly higher in elevation than the Lewis Lake Divide site (a windward site), but the average April 1 snow water equivalent at Lewis Lake Divide is over twice that at Thumb Divide. This same relationship occurs between the snow course at Teton Pass Weather Station and the snow course on top of Snow King Mountain in Jackson. Both are at similar elevations, but the average April 1 SWE at the Teton Pass near the Tetons' crest is about 175 percent of the SWE at Snow King Mountain. The April 1 SWE at the discontinued Moran Bay snow course is double that of the Moran snow course. The Moran course is near the dam on the east side of Jackson Lake and Moran Bay is at about the same elevation on the west side of Jackson Lake and near the base of the Teton Range.

Gros Ventre Summit, near the headwaters of the Gros Ventre River on the east side of the Snake River drainage, receives only about 55 percent of the precipitation that falls at the Phillips Bench site in the Teton Range even though the Gros Ventre Summit site is nearly 600 feet higher in elevation. To accurately estimate the SWE at specific locations in the study area using long-term station data, it is necessary to understand the physical processes associated with orographic uplifting and rain shadow effects. To have GIS models accurately represent these areas, it may be necessary to generate data for supplemental sites in order to replicate the natural processes that are occurring. Average annual precipitation maps were developed to assist with this interpretation.

M O N D H2O WATER													ACCUM.	
													GROWING GROWING	
													DEGDAY DEGDAY	
STATION	H	Y	R	DAY	TMIN	TMAX	TAVG	PPT	SWE	DEPTH	DENSITY	KBDI	F	F
					F	F	F	in.	in.	in.	%			
WY6428	10	1	1983	1	29	46	38	0.25	0.0	6	0	90	0	0
WY6428	10	2	1983	2	29	42	36	0.25	0.0	0	0	65	0	0
WY6428	10	3	1983	3	26	47	36	0.00	0.0	0	0	65	0	0
WY6428	10	4	1983	4	26	46	36	0.00	0.0	0	0	65	0	0
WY6428	10	5	1983	5	26	48	37	0.00	0.0	0	0	65	0	0
WY6428	10	6	1983	6	17	44	30	0.00	0.0	0	0	65	0	0
WY6428	10	7	1983	7	19	53	36	0.00	0.0	0	0	65	0	0
WY6428	10	8	1983	8	19	47	33	0.05	0.0	1	0	65	0	0
WY6428	10	9	1983	9	18	42	30	0.00	0.0	0	0	65	0	0
WY6428	10	10	1983	10	14	47	30	0.00	0.0	0	0	65	0	0
WY6428	10	11	1983	11	16	48	32	0.00	0.0	0	0	65	0	0
WY6428	10	12	1983	12	19	56	38	0.00	0.0	0	0	65	0	0
WY6428	10	13	1983	13	25	62	44	0.00	0.0	0	0	66	3	0
WY6428	10	14	1983	14	26	64	45	0.00	0.0	0	0	67	4	0
WY6428	10	15	1983	15	26	67	46	0.00	0.0	0	0	68	5	0
WY6428	10	16	1983	16	28	67	48	0.00	0.0	0	0	69	7	0
WY6428	10	17	1983	17	25	62	44	0.00	0.0	0	0	70	3	0
WY6428	10	18	1983	18	32	55	44	0.00	0.0	0	0	70	3	0
WY6428	10	19	1983	19	9	55	32	0.00	0.0	0	0	70	0	0
WY6428	10	20	1983	20	10	43	26	0.00	0.0	0	0	70	0	0
WY6428	10	21	1983	21	13	49	31	0.00	0.0	0	0	70	0	0
WY6428	10	22	1983	22	26	56	41	0.00	0.0	0	0	70	0	0
WY6428	10	23	1983	23	24	45	34	0.00	0.0	0	0	70	0	0
WY6428	10	24	1983	24	28	53	40	0.02	0.0	0	0	70	0	0
WY6428	10	25	1983	25	34	47	40	0.02	0.0	0	0	70	0	0
WY6428	10	26	1983	26	34	49	42	0.00	0.0	0	0	70	1	0
WY6428	10	27	1983	27	30	45	38	0.07	0.0	0	0	70	0	0
WY6428	10	28	1983	28	13	40	26	0.00	0.0	0	0	70	0	0
WY6428	10	29	1983	29	15	38	26	0.15	0.2	2	8	70	0	0
WY6428	10	30	1983	30	31	35	33	0.32	0.4	3	13	43	0	0
WY6428	10	31	1983	31	31	39	35	0.15	0.3	1	30	28	0	0
WY6428	11	1	1983	32	27	43	35	0.00	0.0	0	0	28	0	0
WY6428	11	2	1983	33	15	41	28	0.08	0.1	1	8	28	0	0
WY6428	11	3	1983	34	9	36	22	0.00	0.0	0	0	28	0	0
WY6428	11	4	1983	35	12	35	24	0.00	0.0	0	0	28	0	0
WY6428	11	5	1983	36	18	43	30	0.00	0.0	0	0	28	0	0
WY6428	11	6	1983	37	25	46	36	0.00	0.0	0	0	28	0	0
WY6428	11	7	1983	38	24	47	36	0.00	0.0	0	0	28	0	0
WY6428	11	8	1983	39	24	38	31	0.02	0.0	1	2	28	0	0
WY6428	11	9	1983	40	27	40	34	0.00	0.0	0	0	28	0	0
WY6428	11	10	1983	41	8	33	20	0.10	0.1	1	10	28	0	0
WY6428	11	11	1983	42	9	39	24	0.00	0.1	1	10	28	0	0
WY6428	11	12	1983	43	-5	38	16	0.09	0.2	2	10	28	0	0
WY6428	11	13	1983	44	24	28	26	0.02	0.2	3	7	28	0	0
WY6428	11	14	1983	45	-8	33	12	0.00	0.2	4	5	28	0	0
WY6428	11	15	1983	46	-4	29	12	0.00	0.2	2	10	28	0	0
WY6428	11	16	1983	47	1	32	16	0.00	0.0	0	0	28	0	0
WY6428	11	17	1983	48	27	38	32	0.00	0.0	0	0	28	0	0
WY6428	11	18	1983	49	24	45	34	0.00	0.0	0	0	28	0	0

Figure 5. Format of daily data on disk for SNOTEL and climatological stations.

AVERAGE ANNUAL PRECIPITATION MAPS

The average annual precipitation was calculated for SNOTEL and CLIM stations for the 30-year base period from 1961-1990 (Table 7). The annual precipitation at snow courses was estimated using the April 1 SWE versus annual precipitation curve obtained from data at SNOTEL and CLIM stations. Elevation versus average annual precipitation curves were used to determine the elevation at which equal increments of precipitation would occur using various profiles across the drainage (Farnes, 1971). Isohyetal lines (lines of equal precipitation) were drawn connecting known points of annual precipitation. Isohyetal maps for the 1961-1990 period were developed for Snake River drainage above Jackson, Wyoming, of 1:250,000 scale and for Grand Teton National Park on 1:62,500 scale. Copies of the maps are available from the Division of Science and Natural Resource Management at GTNP.

In general, the crest of the Tetons have 60-70 inches of annual precipitation while higher elevations in headwaters of the Gros Ventre River drainage are generally in the 40-50 inch range. The valley areas near Jackson have 16-18 inches precipitation but it increases to about 30 inches near Coulter Bay.

KEETCH-BYRAM DROUGHT INDEX

The Keetch-Byram Drought Index (KBDI) (Keetch and Byram 1988) is a stand-alone drought indicator representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or litter and in upper soil layers. It was initially developed for, and is primarily used for, fire danger ratings. In this study, however, the KBDI is used to represent soil moisture deficiency. KBDI values are important in evaluating forage production by identifying periods of moisture stress and availability of soil moisture through the critical portion of the growing season.

The KBDI varies from 0 to 800, with 0 representing soil moisture at field capacity. The numbers represent 100 times the number of inches of precipitation required to achieve a zero KBDI (or to increase the soil moisture up to field capacity). For example, a KBDI of 300 would require approximately 3 inches of rainfall to bring the soil moisture up to field capacity.

Table 7. Average annual precipitation and April 1 SWE (1961-1990) for stations in and near the Snake River drainage above Jackson, Wyoming.

Site Name	Station Type	Elevation (ft)	Average Annual Precipitation (inches)	Average Annual April 1, SWE (true)
Arizona Creek	SC (Disc)	6820	33.5 ^E	18.4
Aster Creek	SC	7750	47.0 ^E	28.9
Base Camp	SNOTEL	7030	34.0	17.8
Blackrock	SC (Disc)	8900	36.5 ^E	20.4
Coulter Creek	SNOTEL (Disc)	7020	40.9	22.9
Elbo Ranch	SC	7100	23.5 ^E	10.3
Four Mile Meadows	SC	7860	25.5 ^E	12.4
Glade Creek	USBR	7040	38.5	21.9
Grassy Lake	SNOTEL	7265	56.0	36.3
Gros Ventre Summit	SNOTEL	8775	25.8	15.8
Huckleberry Divide	USBR	7300	36.5	20.0
Jackson	CLIM	6230	16.5	2.0(3.7 3/01)
Lewis Lake Divide	SNOTEL	7860	57.0	35.7
Moose	CLIM	6468	21.2	7.2 (8.3 3/01)
Moran	CLIM	6798	24.2	10.1 (10.4 3/01)
Moran Bay	SC (Disc)	6810	36.5 ^E	20.5
Phillips Bench	SNOTEL	8200	44.9	29.4
Pitchstone Plateau	AM (Disc)	8520	70.5 ^E	46.5
Snake River Station	SNOTEL	6920	31.8	19.8
Snow King Mountain	SC	7660	28.0 ^E	14.3
Teton Pass	SC	7740	42.5	25.1
Thumb Divide	SNOTEL	7980	36.6	17.2
Togwotee Pass	SNOTEL	9580	42.8	25.2
Turpin Meadows	SC	6900	22.5 ^E	9.7
Two Ocean Plateau	SNOTEL	9240	46.9	25.3
Younts Peak	SNOTEL	8350	31.4	17.3

SC = Snow Courses; SNOTEL = SNOTEL Site; USBR = US Bureau of Reclamation Telemetry Site; AM = Aerial Markers; CLIM = Climatological Station; Disc = Discontinued; E = Average annual precipitation estimated from April 1 SWE versus annual precipitation curve.

The procedure uses daily precipitation and daily maximum temperature, average annual precipitation, latitude, and KBDI on the previous day as input parameters. For this study, the KBDI is assumed to be zero on the day the snowpack melts to zero. Daily KBDI values are calculated from the time snow melts to zero in the spring until the snow begins to accumulate in the fall or early winter. The value on the day the snow begins to accumulate represents the moisture deficiency in the soil under the snowpack and is assumed to persist until melt begins in the spring.

The KBDI is one factor used in the forage production component of the Index of Winter Severity (IWS).

GROWING DEGREE DAYS

Growing Degree Days (GDD) are calculated as the number of degrees that the mean daily air temperature ($T_{Max} + T_{Min}$ divided by 2) is above 41 °F or 4 °C (the temperature considered to be biological zero for many plants). For this study, it is assumed that plants break dormancy after three consecutive days where the mean daily temperatures are above 41 °F after the snowpack has melted to zero (Farnes *et al.*, 1995).

Degree days are calculated daily from March 1 through September 30 for each year and are accumulated from the time plants are assumed to break dormancy (i.e., three consecutive days where T_{Avg} is above 41 °F). GDD are related to phenological stages of plants. This data is also used in determining the forage production component of the Index of Winter Severity. For this study, it is assumed that the majority of plant growth of native range forage plants occur in the first 750 GDD (Walker *et al.*, 1994).

DEPTH/SWE RELATIONSHIPS

It is more accurate to estimate total snow depth using SWE and the date than it is to estimate snow depth independently due to variability resulting from new snow depth, settlement within the snowpack, the snowpack's prior temperature, and other factors. Historic records of snow course measurements were analyzed to obtain date, density, SWE and depth relationships. Multipliers were developed to calculate snow depth from SWE based on the first-of-the-month snow surveys from January through June and were extrapolated to other dates (Table 8). These multipliers can be applied across the entire study area. Density values can be calculated by dividing the SWE by the snow depth for any specific date at any specific pixel.

Table 8. Multipliers* for calculating snow depth from SWE through the snow season for Grand Teton National Park and Snake River drainage above Jackson, Wyoming.

SWE Inches	DATE								
	Prior to Oct 15	Oct 16 to Nov 15	Nov 16 to Dec 15	Dec 16 to Jan 15	Jan 16 to Feb 14	Feb 15 to Mar 15	Mar 16 to Apr 15	Apr 16 to May 15	May 16 to Jul 31
Less 4.99	7.0	6.5	6.0	5.4	5.0	4.6	4.1	3.2	2.5
5 - 9.99	5.8	5.4	5.0	4.8	4.5	4.0	3.9	2.9	2.3
10 - 14.99	5.0	4.7	4.4	4.2	4.0	3.7	3.5	2.8	2.1
15 - 19.99	4.7	4.4	4.1	3.8	3.7	3.5	3.3	2.6	2.1
20 - 24.99	4.4	4.1	3.9	3.6	3.5	3.3	3.1	2.6	2.1
25 - 29.99	4.2	3.9	3.7	3.5	3.3	3.2	3.0	2.6	2.1
30 - 34.99	4.0	3.8	3.5	3.3	3.2	3.1	2.9	2.5	2.0
35 - 39.99	3.8	3.6	3.4	3.2	3.1	3.0	2.9	2.4	2.0
40 - 44.99	3.7	3.5	3.4	3.1	3.1	3.0	2.8	2.4	2.0
45 - 49.99	3.6	3.5	3.3	3.0	3.0	3.0	2.8	2.4	2.0
50 - 54.99	3.5	3.4	3.2	3.0	3.0	3.0	2.8	2.3	2.0
55 - 59.99	3.5	3.4	3.2	3.0	3.0	3.0	2.8	2.3	2.0
60 - 64.99		3.4	3.2	3.0	3.0	3.0	2.8	2.3	2.0
65 - 69.99			3.2	3.0	3.0	3.0	2.8	2.3	2.0
70 - 74.99				3.0	3.0	3.0	2.8	2.3	2.0
75 - 79.99					3.0	3.0	2.8	2.3	2.0
80 - 84.99						3.0	2.8	2.3	2.0
85 - 89.99							2.8	2.3	2.0
90 - 94.99								2.3	2.0
95 - 99.99									2.0

*SWE x multiplier = snow depth

ANIMALS' TOLERANCE OF SNOW

Many larger ungulates can travel and forage in deeper snow than can smaller animals; however, these larger animals sink further into the snowpack than do most predators and smaller mammals. Most larger mammals (elk, moose, bison) actually sink nearly to the ground surface except when the snow is extremely dense. Because there is less snow under a forest canopy, larger mammals typically use these areas for more efficient travel routes. Also, because south-facing slopes have less snow (due to radiation-induced losses) than do level, non-forested areas and north-facing slopes, animals may utilize south-facing areas when travel becomes difficult in deeper snow. Early in the season, most foraging generally occurs in the relatively flat and non-forested areas with the most abundant forage. Later in the season, these areas may not be accessible due to deeper snow or to the dense snow created by the animals (feeding craters) as they move snow to gain access to forage. Once snow has been disturbed, such as in and around the "craters", it becomes very dense. These areas usually cannot be utilized again until the snow is softened by warm temperatures in the spring. As the winter season progresses, foraging animals are usually forced to move to locations where there is less snow, such as south-facing slopes or lower elevations. Typically the south-facing slopes produce less forage per unit area than do the level sites because lower elevations have deeper soils, more nutrients available and more favorable soil moisture. Generally, these animals will utilize this sparse forage on the south-facing slopes quite quickly and then must move to lower elevations.

Using aerial count data from 1968-1981, SWE maps for the northern range in Yellowstone National Park, and snow tube measurements near animal sightings, Farnes (unpublished) has observed that where bison and elk can migrate to lower snow areas, they will generally forage in areas that have less than 6 inches of SWE. Generally, accumulations of 1 or 2 inches of snow water equivalent are enough to initiate migration of at least part of the herd to lower elevations or areas with less snow. Threshold values for mule deer may be about one-half those for elk.

Values reported in the literature appear to substantiate this value. Most studies report snow depth, rather than snow water equivalent, as a determinant in mammal's habitat use. Where possible, snow depth values were converted to estimated SWE so comparisons between SWE and animal observances could be added to the present data base.

Generally, animals tend to start their migration when snow depth reaches mid-calf height on the leg of a mature animal (estimated 2-3 inches SWE for elk) (Halfpenny and Ozanne, 1989), and a primary stimulus for autumn migration from a summer home range is a snow depth of approximately 25 cm (SWE estimated 1.5 to 2 inches) depending on snow consistency (Skovlin 1982; Rudd *et al.*, 1983; Fischer and Gosson, 1987; see references in Schmidt, 1993). Previous studies in the USSR, Canada and the United States have found snow depths exceeding 40-50 cm (SWE estimated 2.5 to 4 inches) impede the movements of wolves and white-tailed deer (Formozov, 1946; Kelsall, 1969; Mech, 1970; Kelsall and Prescott, 1971).

When snow depths exceed 40 cm (SWE estimated 3 to 4 inches) and basal metabolism is depressed, white-tail deer select forest stands with dense canopy covers and depauperate understories (Pauley *et al.*, 1993). Mule deer use mostly old forest stands (>140 yrs.) as snow depths exceeded 26 cm (SWE estimated 1.5 to 2.5 inches) (Armleder *et al.*, 1994). Moose selection of early winter canopy cover was influenced by both forage and snow depth in a study in British Columbia by Schwab and Pitt (1991). Mean sinking depths were found to be lowest,

and thus movement by deer most favorable, in 80-year old, second growth forest stands (estimated SWE about half of that in openings) (Bunnell et al., 1990).

During periods of snow cover, bighorn sheep in Colorado shifted their feeding areas from open sites to shrub-covered areas, and as snow depth increased, the percentage of green material in their diet declined (Goodson et al., 1991). Larter and Gates (1991) suggest in their study of bison that snow depth influences habitat use.

Huggard (1993) found snow depth could add substantial, density-independent variations to wolf-prey interactions and could affect which classes of prey were killed. Snow depth was determined to be significantly greater during successful coyote kills in Yellowstone National Park (Gese and Grothe, 1995). Snow depth, summed over three consecutive years, was suggested as an important influence on the population parameters of moose in Michigan (Mech et al., 1987).

When low air temperatures (-20° to -50°F) occur during periods without snowfall, a weak layer of snow crystals may develop at the base of the snowpack. The layer is referred to as depth hoar or temperature gradient snow. The surface layer generally breaks rather easily under weight and this weak, low density layer around the forage makes it more available to grazing animals than when the entire snowpack is stronger and more dense. Animals that obtain forage under this weak layer expend less energy than when they must move denser snow. The lower air temperatures at this time, however, require the animals to expend more energy to maintain their body heat.

Snow crusting can also affect foraging animals. Crusts are formed when warmer air temperatures create melt on the snow surface or when there is rainfall on the snowpack followed by freezing air temperatures. Crusts are also formed by wind erosion and deposition. Usually these conditions are highly variable and only portions of the area develop these crusts. The impact on wintering wildlife depends on the time of season, the crust hardness and depth, the extent of the area that is crusted, the duration of these crusts as well as the forage availability.

There may be localized variations in the snowpack due to wind scour or deposition, disturbance by animals, melt, and avalanches. These variables are difficult to predict. For this study, it was acknowledged that these conditions may exist, but the affected areas are usually restricted in size. A refined model to account for all of these variations would require a much greater data base and extensive on-site measurements that are beyond the capability of this study.

INDEX OF WINTER SEVERITY

The Index of Winter Severity (IWS) is obtained by combining SWE, accumulated TMin temperatures below the effective critical temperature for each species, and forage availability on the winter range. The IWS has a scale from +4 to -4, with +4 representing the mildest conditions and -4 indicating the most severe conditions. IWS is calculated for each winter range and each species to represent the variability from the norm of this area. The response of individual animals, or groups of animals, may vary depending on topography and vegetation. The IWS is intended to estimate the response of animals to climatic and vegetative conditions on the winter range. It does not necessarily represent migration response. However, the snow component used in the IWS is one of the variables that does relate to migration.

Snow Water Equivalent

SWE is obtained from SNOTEL or CLIM stations and snow courses. Usually stations on or near each winter range are used for the IWS. As SWE increases, areas available for foraging decrease, energy expended to obtain forage and to travel increases, and competition for forage may increase depending on herd size.

Effective Critical Temperatures

Each species has an effective critical temperature and when air temperatures are below this threshold, the animals must increase their basal metabolic rate to maintain body temperature (Table 9). These values are for non-active periods such as bedding or ruminating and are usually associated with periods having the lowest daily air temperatures. Most wildlife ruminants cannot process enough winter forage to maintain their fat reserves under mild temperature conditions. When air temperatures are below the effective critical temperature, animals must utilize energy from their fat reserves to maintain adequate body temperatures. These losses in fat reserves are accumulative through the winter. For moose and bison, there is no temperature variable in the IWS since their effective critical temperature is so low that only a few days each winter have any effect. However, there is an upper critical temperature where these two species must increase their metabolism in order to reduce their body temperatures. This effect is not considered in this report since they can generally utilize snow cover, shade or inactivity during the warmer part of the day to minimize this effect.

The critical temperature index used in the IWS is calculated by subtracting the effective critical temperature from TMin. If TMin is warmer than the critical temperature, the daily temperature index is zero. Daily values are accumulated from the beginning of the winter, usually weekly or monthly, to determine the season-to-date value. There is some variability within each species related to age, sex, and weight, but the values from Table 9 provide an index related to separate species.

Table 9. Effective critical temperature values for some mammals.

Mammal	°C	°F	Mammal	°C	°F
Pronghorn	0	32	Mountain goat	-20	-4
Whitetail deer	-12	10	Bighorn sheep	-20	-4
Mule deer	-18	0	Moose	-32	-26
Elk	-18	0	Bison	-34*	-29

* Metabolic rates for bison are similar at 0° and -30°C but are about 30 percent higher at +10°C. There was an increase in metabolic rate at -30°C with 3 mph wind indicating a possible effective critical temperature around -34°C (Chappel and Hudson, 1980; Christopherson *et al.*, 1979; Krog and Monson, 1954; Mautz *et al.*, 1985; Nelson and Leege, 1982; Schwab and Pit, 1991; Wesley *et al.*, 1973).

Forage Production

The majority of forage utilized by grazers on the winter range is produced annually, and the amount produced in any year is a function of available spring moisture and temperature. Early growing season moisture comes from snow melt and rainfall, and it is usually adequate for initiating plant growth when temperatures are warm enough to break dormancy. Rainfall later in the growing season, however, is more variable and more significant to total forage production. Moisture falling after July may not be as important in producing forage, particularly if there has been a deficiency in moisture earlier in the season. For the index of winter severity, the amount of forage produced in a given year on the winter range was originally indexed by the June-July precipitation for the summer preceding the winter being indexed. Currently the average daily Keetch-Byram Drought Index (KBDI) for the first 750 growing degree days plus 0.2 times the maximum KBDI during the first 750 GDD is used to represent available soil moisture for forage production. It is assumed the major growth of native forage plants in the study area occurs during this period.

Method

A method used by Shafer and Dezman (1982) was adapted to compare the range of variation in the snow, temperature, and forage in a specific area. This method allows the use of a common scale to compare different variables using the probability of non-exceedence (PN) and to calculate the IWS.

The probability of non-exceedence is obtained by subtracting the normal probability from 100. Using probability of each variable provides a means to compare the variability among variables. To compress the range of probability of non-exceedence (1 - 99%) to a range of -4 to +4, subtract 50 from the probability and divide by 12.25:

$$\text{Index} = \frac{\text{PN} - 50}{12.25}$$

For example, an index for a probability of non-exceedence of 1%, or near worst of record, would be calculated as follows:

$$\frac{1 - 50}{12.25} = \frac{-49}{12.25} = -4$$

An index for a probability of non-exceedence of 50%, or about average, would be calculated as follows:

$$\frac{50 - 50}{12.25} = 0$$

And an index for a probability of non-exceedence of 99%, or near mildest of record, would be calculated like this:

$$\frac{99 - 50}{12.25} = \frac{49}{12.25} = +4$$

The IWS for the winter season for elk was calculated by weighting the snow variable as 45%, the temperature variable as 35%, and the forage variable (KBDI values) as 20%. These weightings come from discussions with various researchers and wildlife managers that suggest the effects of snow should be weighted the largest, temperatures below the effective critical temperature somewhat less, and the total forage production on the winter range should have the least weight. Weightings may be changed to reflect the observations of wildlife managers or for areas not conforming to general wintering ranges. For bison, temperature is not used because their effective critical temperature is near or below the lowest temperatures recorded in this area. For bison, the suggested weighting of snow variable is 70% and the winter forage variable is 30%. For moose, where the winter forage is predominately willow or spruce boughs, the forage production may be weighted over a 2 to 5 year span rather than an index of annual production. Snow and forage weightings are probably similar to bison. For the mule deer, it is suggested the snow variable be weighted as 50%, the critical temperature variable as 30%, and the forage variable as 20%.

From general observation of elk, values above 0 (all + IWS) are comparable (i.e., winter kill is low, reproduction is good, recruitment is good, and predators must work harder to obtain prey). Values between -1 and -2 show some reduction in reproduction but there is generally little mortality of older animals and yearlings. IWS values below -2 usually indicate significant mortality, low reproduction rates, weaker calves and lower birth weights, smaller herd recruitment rates or even negative recruitment (i.e., more animals die than enter the population), and increased predation. IWS values calculated for elk for two winter ranges in and near Grand Teton National Park area are shown in Appendix 4 and in Figures 6 and 7. The IWS values for two winter ranges for bison are tabulated in Appendix 5 and in Figures 8 and 9.

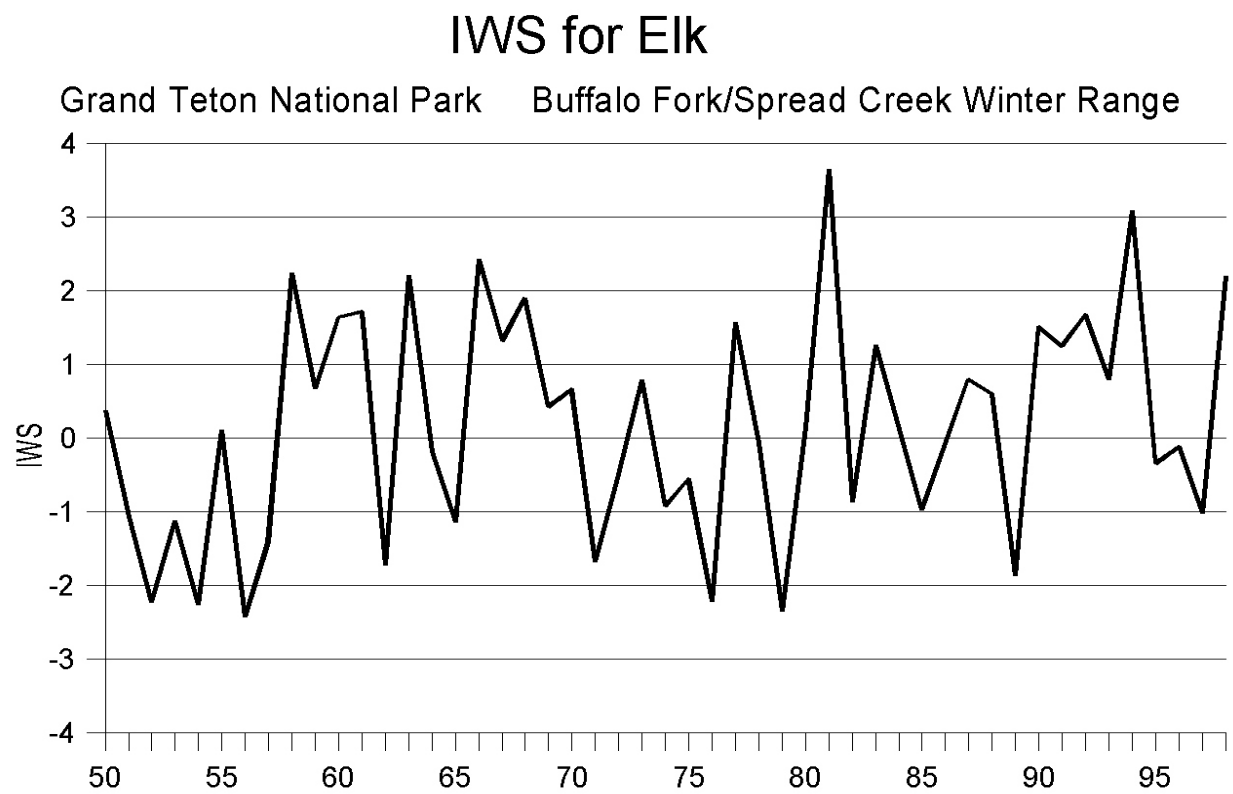


Figure 6. Index of winter severity for elk for the winters of 1950-1998 for the Buffalo Fork/Spread Creek winter range in and near Grand Teton National Park.

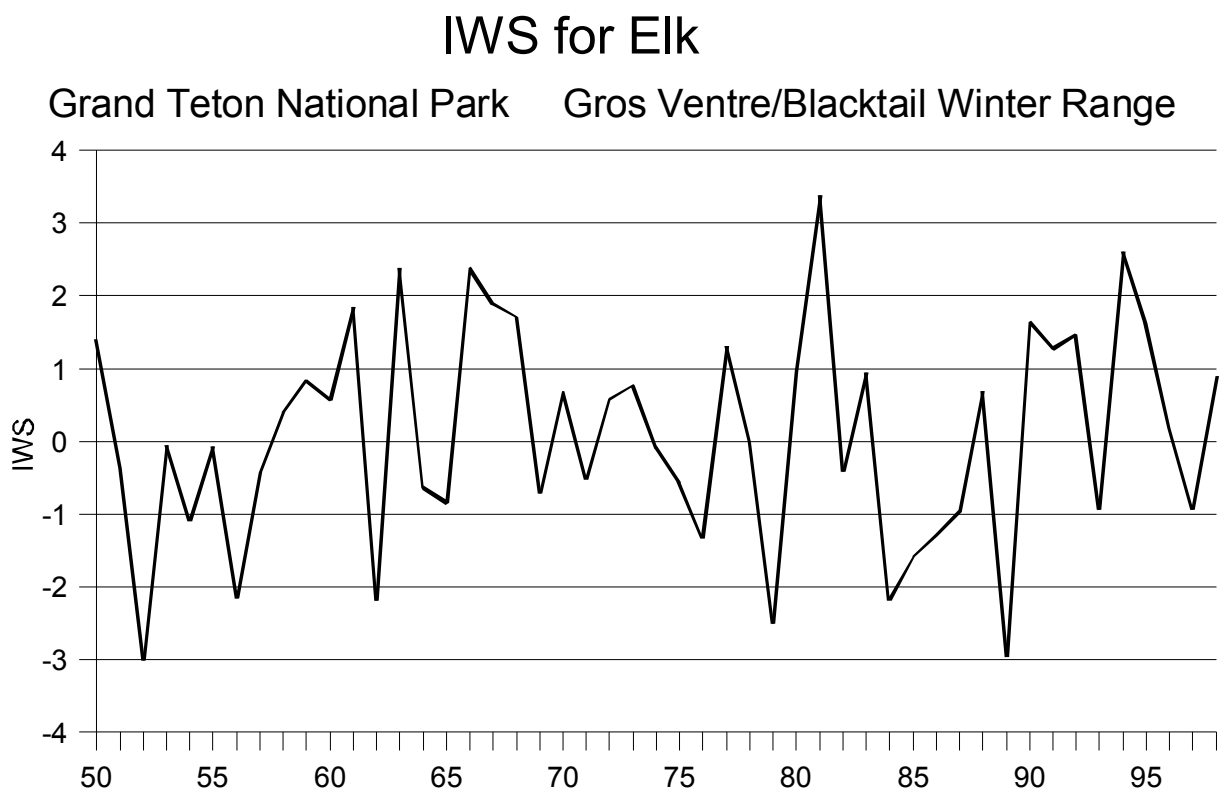


Figure 7. Index of winter severity for elk for the winters of 1950-1998 for the Gros Ventre/Blacktail winter range in and near Grand Teton National Park.

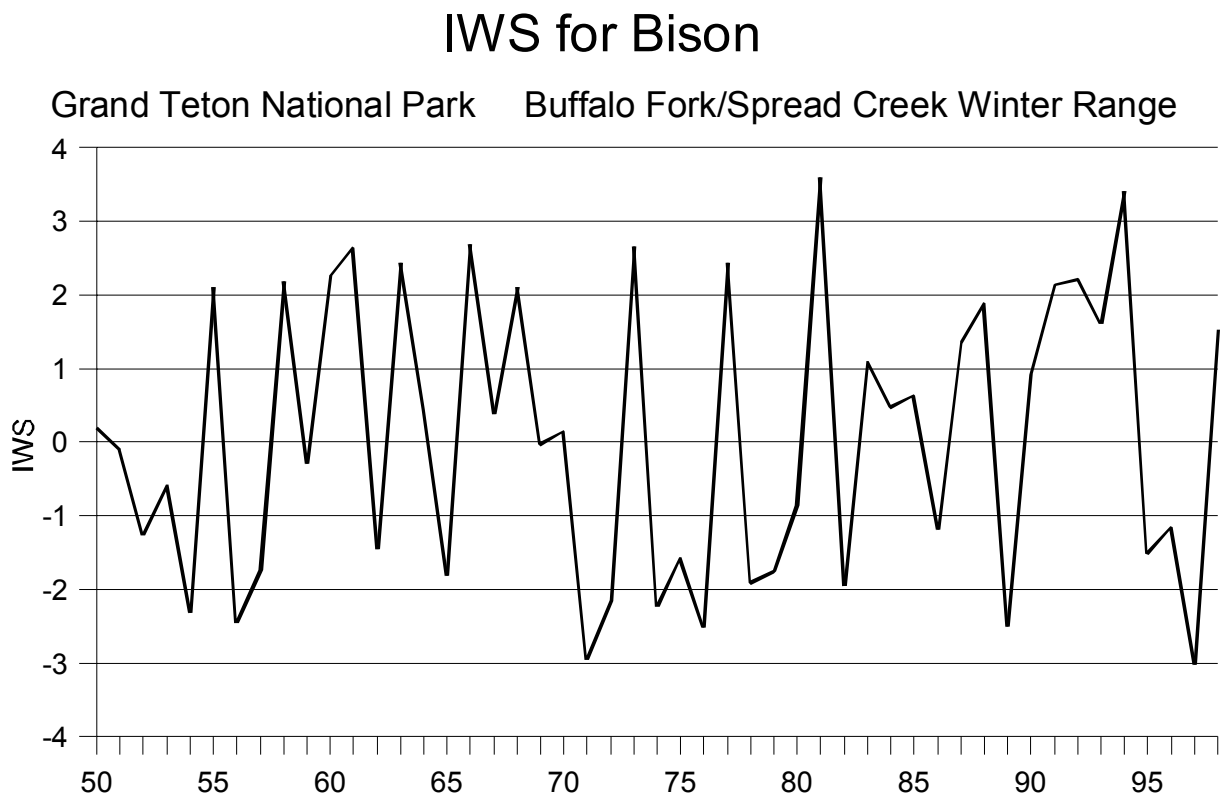


Figure 8. Index of winter severity for bison for the winters of 1950-1998 for the Buffalo Fork/Spread Creek winter range in and near Grand Teton National Park.

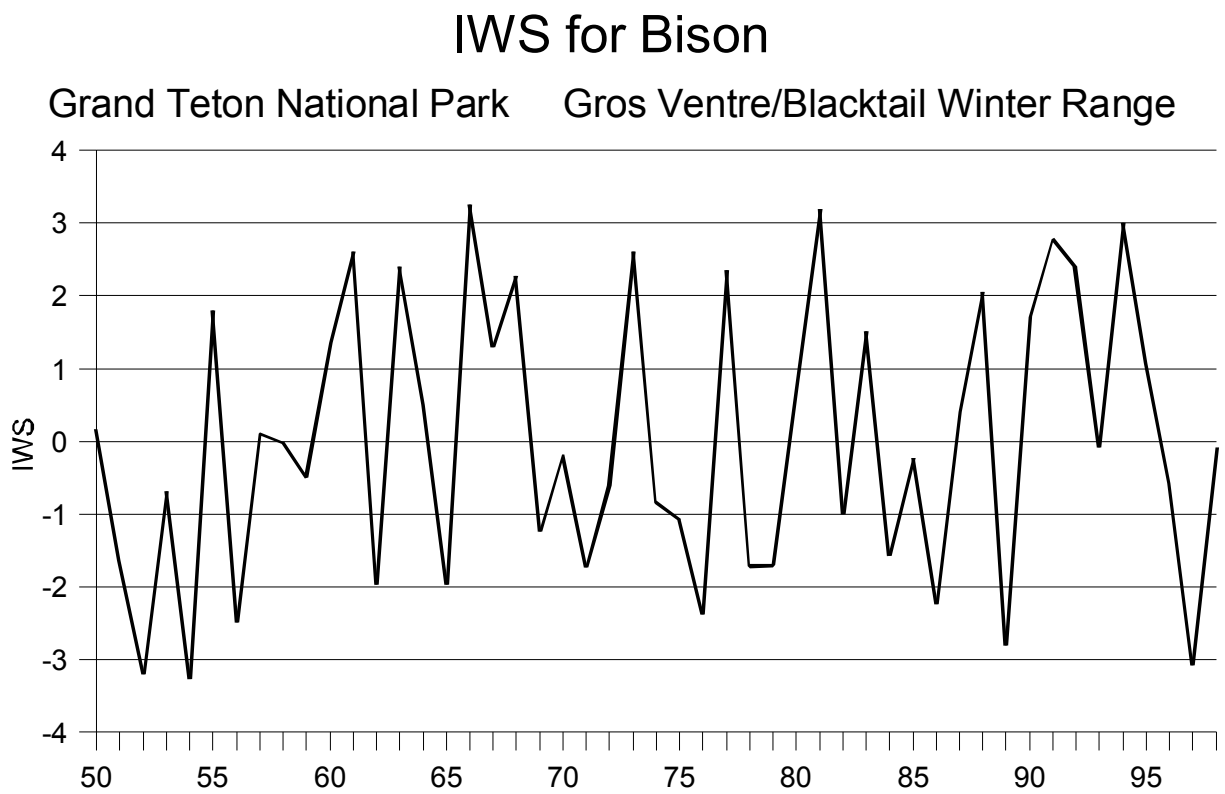


Figure 9. Index of winter severity for bison for the winters of 1950-1998 for the Gros Ventre/Blacktail winter range in and near Grand Teton National Park.

PROCESSING CURRENT DATA

Data Sources

SNOTEL, snow course, and historical climatological data can be downloaded from the NRCS computer in Portland, Oregon. A no-cost agreement and password are needed from the NRCS State Conservationist in Casper, Wyoming. Arrangements for this agreement can be made through the Jackson NRCS office by contacting John Kremer (phone: 307-733-2110). A modem and computer are needed to download this data. Near real-time daily data is available for the SNOTEL sites at Base Camp, Grassy Lake, Gros Ventre Summit, Lewis Lake Divide, Phillips Bench, Snake River Station, Togwotee Pass, Two Ocean Plateau and Younts Peak. Coulter Creek Snotel site was discontinued in September 1996. It should be noted that data in the Portland data base are for the previous 24 hour period. Current snow course data for Aster Creek, Elbo Ranch, Four Mile Meadows, Glade Creek, Huckleberry Divide, Moran, Snow King Mountain, Teton Pass Weather Station, and Turpin Meadow can be downloaded soon after the first of the month surveys from January through May (not all of these sites are measured in January and May).

Climatological (CLIM) station data is observed daily and recorded manually on B91 forms. This data is not usually available electronically until approximately a year after collection. Forms are sent to NWS after the end of each month. Records for Jackson are kept by the Bridger/Teton National Forest Supervisor's office fire staff. Moose records are kept by GTNP Headquarters fire staff at Moose. Moran records are kept by the USBR caretaker at Jackson Lake Dam. At the end of each month, B91s for these locations are mailed to NWS in Riverton, Wyoming (Ray Gomez, phone: 307-857-3827). Snake River climatological records are obtained by South Entrance YNP staff and the B91s are sent to NWS in Riverton and the Chief Ranger's office in Mammoth (YNP). Because of near-real-time availability of SNOTEL records, it is recommended that Snake River Station SNOTEL data be used instead of the data from the CLIM station at Snake River. To use current data from the B91s, it is necessary to input this raw data into electronic form.

Manual snow course monthly measurements are available from the NRCS computer in Portland, Oregon, or the NRCS office in Jackson, Wyoming. For this study, reported SWE values from NRCS for all snow courses have been multiplied by 0.94 to obtain "true" SWE, except for Elbo Ranch which has been multiplied by 0.91.

SWE, precipitation, and snow depth are all reported in inches for SNOTEL, CLIM and snow course data.

Estimating Missing Data

SNOTEL records are usually complete with estimates of any missing values and edits made by NRCS. For CLIM sites, missing values are not estimated by NWS. Correlations have been run between stations and estimating equations are as follows:

Temperature °F

$$\begin{aligned}\text{Jackson TMax} &= \text{Moose TMax} + 2^{\circ} \\ \text{Jackson TMin} &= 0.88 \times \text{Moose TMin} + 3.7^{\circ}\end{aligned}$$

$$\begin{aligned}\text{Moose TMax} &= \text{Moran TMax} - 1^{\circ} \\ &= \text{Jackson TMax} - 2^{\circ} \\ \text{Moose TMin} &= \text{Moran TMin} - 1^{\circ} \\ &= 1.14 \times \text{Jackson TMax} - 3.7^{\circ}\end{aligned}$$

$$\begin{aligned}\text{Moran TMax} &= \text{Moose TMax} + 1^{\circ} \\ &= \text{Snake River TMax} \\ \text{Moran TMin} &= \text{Moose TMin} + 1^{\circ} \\ &= \text{Snake River TMin} + 3^{\circ}\end{aligned}$$

Precipitation:

$$\begin{aligned}\text{Jackson} &= 0.78 \times \text{Moose} \\ \text{Moose} &= 1.28 \times \text{Jackson} \\ &= 0.88 \times \text{Moran} \\ \text{Moran} &= 1.14 \times \text{Moose} \\ &= 0.76 \times \text{Snake River}\end{aligned}$$

Snow Depth:

Generally, estimates of snow depth at CLIM sites are made using records before and after the missing period and extrapolating values based on trends at adjacent stations.

Conversion to Degree Fahrenheit

SNOTEL sites currently report temperature values in °C. All TMax and TMin values for SNOTEL sites are converted to °F using the standard conversion equation ($^{\circ}\text{F} = 1.8 \times ^{\circ}\text{C} + 32$). This is done to ensure compatibility with CLIM station and historical data, which is in °F.

SNOTEL sites also report TAvG as an average of 96 temperature observations (every 15 minutes) over a 24-hour period. To be compatible with CLIM station temperature data, TAvG for SNOTEL sites is calculated as the average of the TMax and TMin values rather than using the reported TAvG values.

Calculating Estimated SWE at CLIM Stations

A program has been written to calculate SWE and densities using data obtained at CLIM stations (Table 4). These calculations are made after all missing data has been estimated.

SNOW IN HUNTER-TALBOT HAYFIELDS AREA

Supplemental snow measurements were taken in the Hunter-Talbot hayfields area in 1996, 1997, and 1998.

Snow was measured across both north-south and east-west transects three times each winter near February 1, March 1, and April 1. The average SWE across these transects was compared to the SWE computed for Moose for the days when Hunter-Talbot measurements were made. This analysis indicated the SWE at Hunter-Talbot could be estimated as 77.8% of the SWE at Moose ($R^2 = .706$, $SE = .75$).

The dates when SWE would reach 2, 4, and 6 inches on the Hunter-Talbot hayfields were estimated using this same relationship (Table 10).

Table 10. Estimated dates when snow water equivalent at Hunter-Talbot hayfields reaches 2, 4, and 6 inches and maximum for the season.

Estimated Dates When SWE is Reached				
Water Year	2 inches	4 inches	6 inches	Max SWE Season (inches)
1949	12/02	12/11	12/30	11.3
1950	01/11	01/22	02/05	11.5
1951	11/20	12/07	01/14	14.0
1952	12/05	12/22	01/12	14.3
1953	12/10	01/05	01/18	10.6
1954	12/20	01/14	01/23	13.2
1955	12/31	01/14	02/17	9.3
1956	12/03	12/16	12/22	17.7
1957	12/11	01/15	02/02	9/2
1958	12/07	12/19	12/29	12.4
1959	12/04	12/12	02/03	8.1
1960	01/13	02/09	03/08	6.6
1961	12/17	02/20	max 5.3- 03/12	5.3
1962	11/23	12/19	01/20	9.7
1963	01/30	03/01	max 4.4 - 03/06	4.4
1964	01/02	01/26	03/12	6.8

Table 10. (continued)

1965	12/01	12/22	12/24	13.1
1966	12/30	02/15	max 4.4 - 03/08	4.4
1967	01/03	01/22	max 5.1 - 02/18	5.1
1968	12/23	01/27	02/23	6.1
1969	12/31	01/19	01/26	8.4
1970	01/13	01/25	max 5.3 - 04/02	5.3
1971	12/09	01/11	02/04	8.6
1972	12/12	01/10	02/13	8.1
1973	12/24	02/12	max 5.4 - 04/01	5.4
1974	11/13	12/18	01/19	8.2
1975	01/08	02/07	02/28	8.7
1976	11/26	12/07	01/13	9.6
1977	02/27	max 2.2 = 03/05	-	2.2
1978	11/26	12/14	12/24	12.8
1979	12/04	12/28	01/15	8.3
1980	01/09	01/14	03/13	6.5
1981	12/27	max 3.7 - 02/19	-	3.7
1982	12/01	12/25	01/03	10.5
1983	12/21	01/05	02/14	7.0
1984	11/26	12/08	01/23	8.0
1985	12/01	02/08	03/27	6.3
1986	11/25	01/03	02/13	9.1
1987	12/20	02/03	max 4.6 - 02/26	4.6
1988	12/11	01/16	max 5.2 - 03/07	5.2
1989	11/16	12/22	01/17	8.8
1990	01/08	01/29	max 5.1 - 03/05	5.1
1991	12/26	03/05	max 4.7 - 03/27	4.7
1992	11/26	02/11	max 4.7 - 02/22	4.7
1993	01/01	02/20	max 5.3 - 03/18	5.3
1994	01/05	02/18	max 5.1 - 02/28	5.1
1995	12/19	01/18	max 5.9 - 03/04	5.9
1996	12/30	01/19	01/28	9.0
1997	12/08	12/22	12/29	12.2
1998	12/09	01/11	01/17	8.9
1949-1998 -	12/18	01/14	01/28	8.2
1961-1990 -	12/19	01/11	01/27	7.2
Earliest/Largest	11/13	12/07	12/22	17.7
Latest/Least	02/27	2 yr less 4"	15 yr less 6"	2.2

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APPENDICES

Appendix 1. Snow water equivalent (in inches) for snow pillows, snow courses, climatological stations and supplemental measurements in the Snake River drainage above Jackson, Wyoming, for February 1, March 1, and April 1 for 1996 through 1998.

Site No.	Site Name	1996			1997			1998		
		Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1
SNOW PILLOWS										
101	Base Camp	17.5	21.9	25.0	23.8	26.6	30.1	13.4	14.7	16.5
102	Coulter Creek	19.8	26.8	30.8	27.3	31.3	35.5	-	-	-
103	Glade Creek	18.7	23.8	27.3	27.4	30.6	35.0	15.0	16.9	20.4
104	Grassy Lake	24.1	31.4	37.9	37.2	40.4	46.1	23.9	26.7	30.9
105	Gros Ventre Summit	13.8	15.6	18.6	17.9	19.1	22.5	7.4	9.0	11.9
106	Huckleberry Divide	17.3	21.4	24.8	22.4	24.9	29.4	13.9	15.7	19.0
107	Lewis Lake Divide	31.8	42.0	48.3	44.9	48.0	53.0	21.0	24.0	30.2
108	Moran (Jackson Dam)	11.6	13.7	14.7	14.2	15.8	17.6	12.9	14.1	14.2
109	Phillips Bench	25.5	33.5	36.0	33.1	36.2	42.1	19.0	22.5	26.6
110	Snake River Station	14.3	18.6	21.3	22.2	25.6	29.1	12.7	14.1	17.7
111	Thumb Divide	16.7	21.0	25.7	26.0	28.6	32.6	11.2	13.1	16.1
112	Togwotee Pass	24.0	29.3	33.4	27.4	30.5	34.8	17.3	22.1	25.4
113	Two Ocean Plateau	28.5	35.2	40.6	35.7	39.1	45.2	20.1	22.4	27.5
114	Younts Peak	18.4	21.7	23.6	18.5	20.6	24.1	11.6	12.5	14.8
SNOW COURSES*										
201	Aster Creek	27.9	36.1	39.1	36.1	41.4	46.2	19.0	22.7	23.9
202	Elbo Ranch	7.5	11.6	13.2	13.5	14.1	16.6	8.2	11.5	9.8
203	Four Mile Meadows	10.9	12.7	14.5	12.5	15.0	15.8	7.9	9.2	9.5
204	Glade Creek	18.0	22.7	24.2	25.6	29.0	32.5	15.1	17.2	20.2
205	Huckleberry Divide	17.4	22.0	25.1	21.6	25.3	26.7	13.0	15.7	16.9
206	Moran	10.3	13.0	13.7	14.9	17.1	16.7	11.0	11.9	10.8
207	Snake River Station	15.6	19.7	22.2	20.7	26.9	26.5	13.3	14.9	17.2
208	Snow King Mountain	11.9	14.5	16.4	16.5	17.4	19.5	9.8	12.2	12.2
209	Teton Pass WS	24.1	28.0	32.9	36.1	36.9	40.8	19.3	21.2	24.3
210	Turpin Meadows	9.3	11.8	12.0	12.5	14.6	14.9	8.1	8.6	8.6

Appendix 1. (continued)

Site No.	Site Name	1996			1997			1998		
		Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1
CLIMATOLOGICAL STATIONS										
301	Jackson	2.5	2.9	0.0	4.5	4.6	0.0	6.4	7.7	0.0
302	Moose	8.8	10.6	8.6	13.0	14.8	13.6	10.7	12.6	11.2
303	Moran	8.6	10.5	8.7	15.9	17.3	15.2	11.4	12.4	11.9
SUPPLEMENTAL MEASUREMENTS*										
01	Boys Ranch	14.6	15.8	16.0	17.7	18.5	20.6	12.2	14.3	12.6
02	Death Canyon	16.5	17.1	16.6	23.4	25.3	23.5	13.2	15.6	16.2
03	R Lazy S	10.2	12.5	13.9	14.6	16.4	17.2	11.9	13.3	12.0
04	Wilson Road	12.4	14.1	14.1	17.5	20.3	17.5	12.4	14.1	12.1
05	Moose W.S.	10.0	9.7	6.8	12.3	14.0	13.2	9.5	10.4	8.5
06	Beaver Creek	13.6	15.1	11.3	16.1	20.5	20.0	11.9	12.6	11.2
07	Blacktail Butte	8.9	11.0	11.6	10.8	13.8	13.3	10.0	11.0	9.4
08	Deadmans Bar Road	7.5	8.2	8.9	10.8	13.8	11.2	9.8	11.2	10.0
09	Moosehead Ranch	5.8	5.7	4.2	4.7	4.7	3.6	7.1	7.6	6.0
10	N. Elk Ranch	6.1	6.2	4.7	8.2	8.9	9.0	8.3	8.4	8.2
11	Buffalo R.S.	7.8	8.1	8.8	9.8	12.1	12.8	9.3	9.1	9.7
12	Oxbow Bend	9.7	10.3	10.4	14.1	17.5	18.1	10.7	11.7	11.3
13	Buffalo Valley Road	-	-	-	2.4	1.5	0.0	2.6	4.4	0.0
14	Road 30083	4.9	5.5	6.7	10.6	10.4	11.1	6.7	8.5	7.4
15	Buffalo Run	5.7	5.8	5.0	8.5	10.0	10.2	7.2	7.9	7.3
16	KOA Picnic Area	-	-	-	5.6	7.2	4.9	6.0	6.4	5.8
17	Black Rock R.S.	6.3	6.6	6.5	8.4	9.1	10.3	6.1	7.2	7.5
18	Antelope Flat	4.8	5.4	5.0	8.9	9.6	8.0	9.2	7.3	5.3
19	Mailbox Corner	6.7	7.6	8.0	12.1	13.6	11.6	7.1	8.3	5.9
20	Schwering Studio	7.8	8.8	6.6	7.3	10.2	9.6	5.7	7.2	7.7
21	Lobo Hill	-	-	-	7.8	8.9	8.5	5.6	8.2	7.8
22	Highlands Junction	4.9	5.5	6.1	5.8	6.8	5.9	5.3	5.0	5.0
23	Highlands Loop	3.8	4.3	5.2	5.7	6.6	9.6	4.7	6.1	5.9
24	Airport	3.5	4.5	2.0	6.4	6.5	4.7	6.4	7.0	5.4

Appendix 1. (continued)

Site No.	Site Name	1996			1997			1998		
		Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1	Feb 1	Mar 1	Apr 1
25	Gros Ventre River	6.0	6.8	6.0	5.9	6.8	5.9	5.1	7.0	5.8
26	Gros Ventre Turnout	4.9	5.5	3.6	4.8	6.0	2.6	5.0	5.8	3.1
27	Fish Hatchery	2.9	3.3	0.0	3.8	4.2	0.0	5.0	7.0	3.9
28	Jackson W.S.	2.9	3.3	0.0	4.2	4.5	0.0	4.5	5.7	1.9
29	NER Headquarters	3.4	5.6	0.0	3.8	4.4	0.0	4.6	5.7	0.0
30	Lupin Meadows	14.2	16.2	15.8	13.5	16.8	18.0	13.6	13.8	14.5
31	Jenny Lake Lodge	17.8	22.4	23.8	20.8	24.0	24.8	15.7	17.0	18.3
32	N. Jenny Lake Junction	15.1	17.5	16.8	20.3	24.0	25.6	14.5	17.5	18.0
33	Sewage Ponds	11.3	12.2	11.5	16.8	17.7	18.0	11.3	11.8	12.3
34	Moran Bay S.C.	20.3	23.2	23.9	-	-	-	-	-	-
35	Pilgrim Creek	13.5	15.6	14.4	17.4	20.0	22.0	11.9	12.4	15.0
36	Coulter Bay	12.5	14.5	13.5	17.6	20.2	21.5	13.1	11.8	14.9
37	Lizard Creek	16.0	18.5	17.8	19.8	22.2	24.6	11.6	13.0	14.9
38	Flagg Ranch	12.6	14.6	14.3	18.4	22.3	26.3	11.4	12.8	15.5
39	Hunters Hayfield W-E	8.4	9.5	8.5	9.8	10.0	10.6	7.3	9.0	6.7
40	Hunters Hayfield N-S	6.3	7.1	8.5	10.5	10.3	11.4	7.0	8.5	7.4
41	Bar BC Road	9.9	11.3	10.9	16.1	17.4	15.9	11.7	13.3	10.8
42	Bar BC Road B	8.3	8.9	8.9	-	-	-	-	-	-
43	Bar BC Mid	10.9	11.6	11.5	-	-	-	-	-	-
44	Bar BC FP	8.4	9.0	9.0	-	-	-	-	-	-
45	Bar BC Mid Road	10.0	10.6	10.6	-	-	-	-	-	-
46	RKORoad Flats	10.2	11.4	12.6	-	-	-	-	-	-
47	RKO PL	6.5	7.3	6.7	-	-	-	-	-	-
48	RKO Willow Flat	5.9	6.4	5.4	-	-	-	-	-	-
49	Ski Area Base	-	-	-	14.8	16.7	15.9	8.1	8.9	8.1
50	Phillips Canyon	-	-	-	26.5	26.3	27.3	12.0	14.4	15.5

* Adjusted to represent “true” SWE

Appendix 2. Average February 1, March 1, and April 1 snow water equivalent for snow pillows, snow courses, climatological stations and supplemental measurements in the Snake River Drainage above Jackson, Wyoming, for 1961-1990

Site No.	Site Name	1961-1990 Average SWE, Inches		
		Feb 1	Mar 1	Apr 1
SNOW PILLOWS				
101	Base Camp	12.5	15.7	17.8
102	Coulter Creek	14.6	19.8	22.9
103	Glade Creek	14.5	18.9	21.9
104	Grassy Lake	23.0	29.6	36.3
105	Gros Ventre Summit	10.6	12.9	15.8
106	Huckleberry Divide	13.2	17.2	20.0
107	Lewis Lake Divide	22.8	29.5	35.7
108	Moran (Jackson Dam)	10.0	12.6	13.6
109	Phillips Bench	19.4	24.2	29.4
110	Snake River Station	12.6	15.7	17.6
111	Thumb Divide	11.4	14.3	17.2
112	Togwotee Pass	16.9	20.8	25.2
113	Two Ocean Plateau	18.2	22.4	25.3
114	Younts Peak	12.2	14.8	17.3
SNOW COURSES*				
201	Aster Creek	18.8	23.8	28.9
202	Elbo Ranch	7.4	9.3	10.3
203	Four Mile Meadows	8.4	10.4	12.4
204	Glade Creek	14.7	19.1	22.2
206	Huckleberry Divide	13.5	17.6	20.4
206	Moran	8.7	11.1	11.9
207	Snake River Station	13.2	17.1	19.8
208	Snow King Mountain	9.5	12.0	14.3
209	Teton Pass WS	16.3	21.1	25.1
210	Turpin Meadows	7.1	8.9	9.7

Appendix 2. (continued)

Site No.	Site Name	1961-1990 Average SWE, Inches		
		Feb 1	Mar 1	Apr 1
CLIMATOLOGICAL STATIONS				
301	Jackson	3.3	3.7	2.0
302	Moose	6.7	8.3	7.2
303	Moran	8.4	10.4	10.1
SUPPLEMENTAL MEASUREMENTS*				
01	Boys Ranch	10.4	12.0	12.6
02	Death Canyon	12.4	14.3	14.9
03	R Lazy S	8.5	10.4	11.0
04	Wilson Road	9.8	12.0	12.2
05	Moose W.S.	6.7	8.3	7.2
06	Beaver Creek	9.3	12.1	12.2
07	Blacktail Butte	6.9	8.8	8.8
08	Deadmans Bar Road	6.6	8.4	8.0
09	Moosehead Ranch	4.2	4.7	3.9
10	N. Elk Ranch	5.4	6.0	5.9
11	Buffalo R.S.	6.3	7.5	8.2
12	Oxbow Bend	8.1	10.1	10.8
13	Buffalo Valley Road	-	-	-
14	Road 300383	5.2	6.2	6.6
15	Buffalo Run	5.0	6.0	5.9
16	KOA Picnic Area	4.0	5.0	4.1
17	Black Rock R.S.	4.9	5.8	6.3
18	Antelope Flat	4.3	5.5	4.7
19	Mailbox Corner	6.0	7.3	6.5
20	Schwering Studio	4.8	6.5	6.1
21	Lobo Hill	4.6	6.2	6.4
22	Highlands Junction	3.8	4.4	4.6
23	Highlands Loop	3.4	4.3	5.1
24	Airport	3.9	4.6	3.3

Appendix 2. (continued)

Site No.	Site Name	1961-1990 Average SWE, Inches		
		Feb 1	Mar 1	Apr 1
25	Gros Ventre River	4.0	5.2	4.8
26	Gros Ventre Turnout	3.5	4.4	2.5
27	Fish Hatchery	3.4	3.9	3.0
28	Jackson W.S.	3.3	3.7	2.0
29	NER Headquarters	3.3	3.7	2.0
30	Lupin Meadows	9.3	11.9	13.1
31	Jenny Lake Lodge	12.4	16.2	18.3
32	N. Jenny Lake Junction	11.4	15.1	16.6
33	Sewage Ponds	9.3	10.7	11.6
34	Moran Bay S.C.	13.7	17.9	20.5
35	Pilgrim Creek	10.0	12.3	13.8
36	Coulter Bay	10.2	12.0	13.4
37	Lizard Creek	11.6	14.4	16.1
38	Flagg Ranch	11.0	13.8	16.6
39	Hunters Hayfield W-E	5.4	7.0	6.6
40	Hunters Hayfield N-S	5.0	6.4	7.0
41	Bar BC Road	8.4	10.6	10.0
42	Bar BC Road B	-	-	-
43	Bar BC Mid	-	-	-
44	Bar BC FP	-	-	-
45	Bar BC Mid Road	-	-	-
46	RKO Road Flats	9.1	10.5	11.4
47	RKO PL	5.4	6.2	5.8
48	RKO Willow Flat	5.0	5.5	4.7
49	Ski Area Base	6.6	8.6	8.1
50	Phillips Canyon	11.1	13.6	14.4

*Adjusted to represent “true” SWE

Appendix 3. Summary of snow accumulation, KBDI, and growing degree-days for sites in the Snake River drainage above Jackson, Wyoming , for sites having daily climatological data.

1961-1990 Average Snow Accumulation				
Site Name	Day Snow Starts	Max SWE (inches)	Day Max SWE	Day Snow Ends
Base Camp	10/31	18.9	4/06	5/18
Coulter Creek	10/28	24.3	4/03	5/21
Glade Creek	10/28	22.8	4/03	5/18
Grassy Lake	10/22	38.3	4/11	6/06
Gros Ventre Summit	10/17	17.6	4/24	5/30
Huckleberry Divide	10/28	21.2	4/12	5/18
Jackson	11/28	4.4	3/01	3/31
Lewis Lake Divide	10/27	37.9	4/17	6/11
Moose	11/14	9.0	3/22	4/24
Moran	11/11	11.6	3/25	5/04
Phillips Bench	10/22	33.4	4/29	6/11
Snake River Station	11/06	19.0	4/03	5/12
Thumb Divide	10/25	18.5	4/17	5/25
Togwotee Pass	10/07	30.7	5/08	6/26
Two Ocean Plateau	10/07	29.6	5/08	7/02
Younts Peak	10/09	19.4	4/29	6/08

Appendix 3. (continued)

1961-1990 Average Accumulation of Growing Degree-Days (above 41°F) after Snow is Zero and after Three Consecutive Days with TAv _g above 41°F.								
Site Name	Start Accum	Day 750 GDD	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Sep 30
Base Camp	5/29	7/24	0	26	339	876	1366	1579
Coulter Creek	5/19	7/15	0	75	452	1051	1587	1854
Grassy Lake	6/06	8/02	0	0	204	728	1183	1400
Gros Ventre Summit	5/31	8/08	0	0	250	641	1067	1224
Jackson	4/23	7/07	32	224	638	1268	1820	2095
Lewis Lake Divide	5/31	7/24	0	0	285	883	1417	1688
Moose	5/03	7/11	13	184	577	1185	1733	2006
Moran	5/10	7/15	0	117	476	1056	1604	1843
Phillips Bench	6/14	7/28	0	0	216	810	1345	1609
Snake River Station	5/18	7/18	0	72	420	975	1462	1680
Thumb Divide	5/28	8/01	0	0	272	752	1164	1345
Togwotee Pass	6/28	10/03	0	0	11	341	632	740
Two Ocean Plateau	7/01	9/23	0	0	0	323	655	788
Younts Peak	6/11	8/09	0	0	169	634	1043	1206

Appendix 3. (continued)

1961-1990 Average Daily Keetch-Byram Drought Index									
Site Name	Maximum for Month						Avg. 0-750 GDD	Max. 0-750 GDD	Max Season
	Apr	May	Jun	Jul	Aug	Sept			
Base Camp	3	29	118	284	381	372	112	246	403
Coulter Creek	2	26	120	303	365	353	100	264	419
Grassy Lake	0	14	130	377	478	435	172	380	483
Gros Ventre Summit	0	3	52	157	210	194	67	171	218
Jackson	16	42	99	222	274	274	35	126	299
Lewis Lake Divide	0	13	122	333	445	409	167	357	486
Moose	8	40	101	223	295	291	44	145	321
Moran	3	29	98	219	290	292	54	165	314
Phillips Bench	0	6	89	285	362	348	130	266	388
Snake River Station	2	29	111	258	333	316	87	232	352
Thumb Divide	0	14	83	224	298	280	108	257	339
Togwotee Pass	0	0	18	115	137	132	70	154	158
Two Ocean Plateau	0	0	18	125	189	169	97	208	217
Younts Peak	0	1	54	160	211	184	80	193	221

Appendix 4. Index of winter severity (IWS) values for elk for Grand Teton National Park winter ranges, 1949-1998.

Winter	Buffalo Fork/Spread Creek				Gros Ventre/Blacktail			
	Jan 1	Feb 1	Mar 1	Season	Jan 1	Feb 1	Mar 1	Season
49-50	3.19	2.44	1.13	0.38	3.23	2.42	2.14	1.86
50-51	0.33	-0.69	-1.03	-1.06	0.67	-0.71	-0.39	-0.76
51-52	-2.36	-1.64	-1.94	-2.23	-1.85	-1.76	-2.51	-2.46
52-53	-0.65	-1.03	-1.71	-1.12	-1.42	-0.39	-0.43	-1.63
53-54	-0.32	-1.04	-1.33	-2.26	0.91	-0.20	-0.67	-1.17
54-55	1.47	1.43	0.99	0.11	0.72	1.16	0.45	-0.20
55-56	-2.05	-1.60	-2.22	-2.42	-1.37	-1.13	-1.70	-1.37
56-57	-0.39	-1.35	-1.33	-1.41	-0.62	-1.68	-0.64	-1.68
57-58	0.76	1.40	1.75	2.25	-1.10	-0.57	-0.04	2.06
58-59	0.69	0.75	0.53	0.67	0.41	0.74	0.68	0.95
59-60	2.59	2.27	1.61	1.64	2.10	1.68	0.69	1.00
60-61	0.45	0.76	1.39	1.72	0.72	1.08	1.55	0.25
61-62	-2.27	-1.87	-1.59	-1.72	-1.77	-2.07	-2.22	-2.12
62-63	2.71	1.91	2.27	2.21	2.77	1.54	2.28	1.92
63-64	2.29	0.87	0.58	-0.18	2.18	0.81	0.29	0.25
64-65	-0.79	-0.29	-0.38	-1.14	-0.79	-0.48	-0.38	1.33
65-66	2.65	2.28	2.54	2.43	2.28	2.53	2.45	2.60
66-67	1.19	0.95	1.03	1.32	0.85	1.33	1.59	2.02
67-68	1.20	1.58	1.42	1.90	-0.00	0.99	1.31	1.60
68-69	0.53	0.13	0.45	0.43	0.86	-0.41	-0.30	1.37
69-70	1.97	0.14	0.67	0.67	1.00	-0.46	0.47	1.40
70-71	-1.41	-1.35	-1.15	-1.68	0.04	-0.30	0.17	-0.15
71-72	-0.52	-0.83	-0.82	-0.49	0.37	-0.03	0.13	0.81
72-73	-0.44	0.42	0.65	0.79	0.33	0.89	0.81	-0.71
73-74	-0.04	-0.39	-0.46	-0.92	0.05	-0.41	-0.25	0.58
74-75	1.20	0.68	-0.04	-0.55	0.75	0.46	-0.35	0.22
75-76	-0.56	-1.23	-1.39	-2.22	0.36	0.86	-0.57	-0.42
76-77	1.60	1.18	1.43	1.57	1.25	1.08	1.12	-0.01
77-78	-0.62	-0.48	-0.34	-0.06	-0.10	0.05	-0.17	1.53
78-79	-2.99	-2.90	-2.87	-2.35	-2.60	-2.61	-2.56	-3.20
79-80	1.18	0.15	0.52	0.15	1.36	0.30	0.93	0.01
80-81	3.06	3.54	3.57	3.65	2.77	3.24	3.32	3.47
81-82	-0.17	-0.38	-1.10	-0.87	0.22	0.10	-0.68	0.48
82-83	-0.47	0.94	1.16	1.27	-0.79	0.96	0.44	0.87
83-84	-1.64	-0.27	-0.13	0.12	-3.57	-2.38	-2.32	-1.05
84-85	-2.36	-0.65	-0.82	-0.97	-1.52	-0.67	-0.68	-2.37
85-86	0.18	0.70	-0.75	-0.07	-1.80	-1.29	-1.81	1.10
86-87	-0.94	-0.30	0.47	0.81	-1.56	-1.34	-1.15	-1.03
87-88	-0.06	0.19	0.26	0.61	0.74	0.67	0.69	-0.54
88-89	-0.73	-1.25	-1.63	-1.87	-2.77	-2.79	-2.89	-1.81
89-90	1.58	0.95	1.09	1.52	1.58	1.27	1.24	1.02
90-91	-0.37	0.42	1.29	1.26	-0.09	0.56	1.21	-0.26
91-92	-0.87	0.50	1.14	1.68	-1.09	0.36	1.18	-0.14
92-93	-0.06	0.54	0.44	0.79	-0.18	-0.16	-0.93	-0.17
93-94	2.20	2.94	2.76	3.09	1.51	2.77	2.39	2.65
94-95	-0.79	-0.86	0.42	-0.34	0.41	0.44	1.63	-0.19
95-96	0.59	-0.18	-0.32	-0.11	2.57	0.77	0.05	1.04
96-97	-0.88	-0.91	-1.18	-1.02	-0.69	-0.99	-0.97	0.48
97-98	1.96	0.93	1.87	2.20	0.60	0.60	0.60	2.55

Appendix 5. Index of winter severity (IWS) values for bison for Grand Teton National Park winter ranges, 1949-1998.

Winter	Buffalo Fork/Spread Creek				Gros Ventre/Blacktail			
	Jan 1	Feb 1	Mar 1	Season	Jan 1	Feb 1	Mar 1	Season
49-50	3.41	2.29	1.32	0.19	3.01	1.71	1.37	0.17
50-51	-0.41	0.01	-0.54	-0.10	-0.77	-1.85	-1.86	-1.63
51-52	-2.78	-1.00	-0.85	-1.26	-2.94	-2.71	-2.90	-3.20
52-53	1.19	-1.22	-1.47	-0.57	-0.53	-1.28	-1.25	-0.68
53-54	-0.09	-1.75	-1.96	-2.31	0.14	-1.87	-2.85	-3.27
54-55	3.00	3.29	2.98	2.10	1.81	2.81	2.10	1.80
55-56	-2.63	-2.63	-2.53	-2.45	-2.55	-2.57	-2.53	-2.49
56-57	-0.56	-0.77	-1.47	-1.73	-0.02	-0.95	-0.03	0.10
57-58	0.62	1.92	1.47	2.19	-1.21	-0.42	-0.51	-0.02
58-59	-0.54	-0.05	-0.73	-0.30	-1.20	-0.48	-0.75	-0.49
59-60	2.71	2.73	2.37	2.25	1.87	2.15	1.59	1.35
60-61	1.39	2.47	2.45	2.64	1.54	2.61	2.50	2.61
61-62	-2.59	-1.28	-1.32	-1.46	-2.21	-1.61	-2.22	-1.97
62-63	2.51	2.32	2.10	2.43	2.43	1.80	2.20	2.40
63-64	2.08	0.84	1.53	0.45	2.31	1.27	1.78	0.50
64-65	-2.17	-2.07	-1.87	-1.82	-2.24	-2.19	-2.04	-1.96
65-66	2.29	1.97	2.56	2.68	2.09	2.81	3.04	3.26
66-67	1.27	-0.08	-0.02	0.38	1.17	0.81	0.93	1.30
67-68	2.50	2.38	1.73	2.11	0.84	1.84	2.03	2.28
68-69	-0.04	-1.18	-0.78	-0.03	1.19	-1.83	-1.59	-1.24
69-70	2.36	-0.63	0.02	0.15	0.70	-1.41	-0.44	-0.17
70-71	-2.66	-2.78	-2.45	-2.96	-0.83	-1.38	-1.06	-1.73
71-72	-1.45	-2.30	-2.41	-2.16	-0.55	-1.39	-1.13	-0.61
72-73	1.29	2.20	2.58	2.66	2.26	2.82	2.83	2.60
73-74	-1.56	-1.54	-1.49	-2.24	-1.62	-1.55	-0.89	-0.85
74-75	0.93	0.19	-0.71	-1.57	0.93	0.34	-0.55	-1.08
75-76	-1.53	-2.05	-2.12	-2.52	-0.02	-0.01	-2.09	-2.37
76-77	2.34	2.36	2.47	2.44	2.15	2.34	2.35	2.36
77-78	-2.23	-2.25	-2.28	-1.91	-1.84	-1.63	-1.87	-1.71
78-79	-2.43	-2.29	-2.39	-1.76	-1.85	-1.84	-1.77	-1.70
79-80	1.36	-0.08	-0.06	-0.86	2.06	0.60	0.93	0.71
80-81	2.81	3.47	3.53	3.60	2.53	3.05	3.16	3.20
81-82	-1.74	-2.00	-1.97	-1.96	-1.02	-1.15	-1.09	-1.00
82-83	0.22	1.11	1.24	1.10	0.52	1.93	1.06	1.52
83-84	-1.67	0.08	0.47	0.47	-3.67	-1.97	-1.66	-1.57
84-85	-1.59	1.09	0.89	0.63	-0.24	1.13	1.16	-0.23
85-86	0.51	0.92	-1.84	-1.19	-2.25	-1.49	-2.64	-2.23
86-87	-0.07	0.57	1.22	1.35	-0.39	-0.12	0.25	0.41
87-88	0.97	1.49	1.56	1.88	1.67	1.89	2.09	2.06
88-89	-1.52	-1.97	-1.81	-2.50	-3.39	-2.96	-2.55	-2.80
89-90	0.86	-0.11	0.42	0.92	2.01	1.03	1.35	1.70
90-91	1.32	2.24	2.71	2.14	1.95	2.69	3.03	2.78
91-92	0.22	1.83	1.94	2.21	0.04	1.78	2.34	2.39
92-93	0.06	1.07	1.23	1.61	0.59	0.35	-0.13	-0.09
93-94	3.00	3.34	3.17	3.41	2.75	3.38	2.99	3.01
94-95	-1.39	-1.12	-0.18	-1.52	0.04	0.34	1.28	1.07
95-96	-0.38	-1.17	-1.24	-1.15	2.24	0.03	-0.64	-0.57
96-97	-3.15	-3.12	-3.05	-3.03	-2.91	-3.24	-3.03	-3.07
97-98	2.27	-0.17	0.99	1.52	1.68	-0.13	-0.56	-0.09